JUNE 1986 VOL. 8 NO. 6

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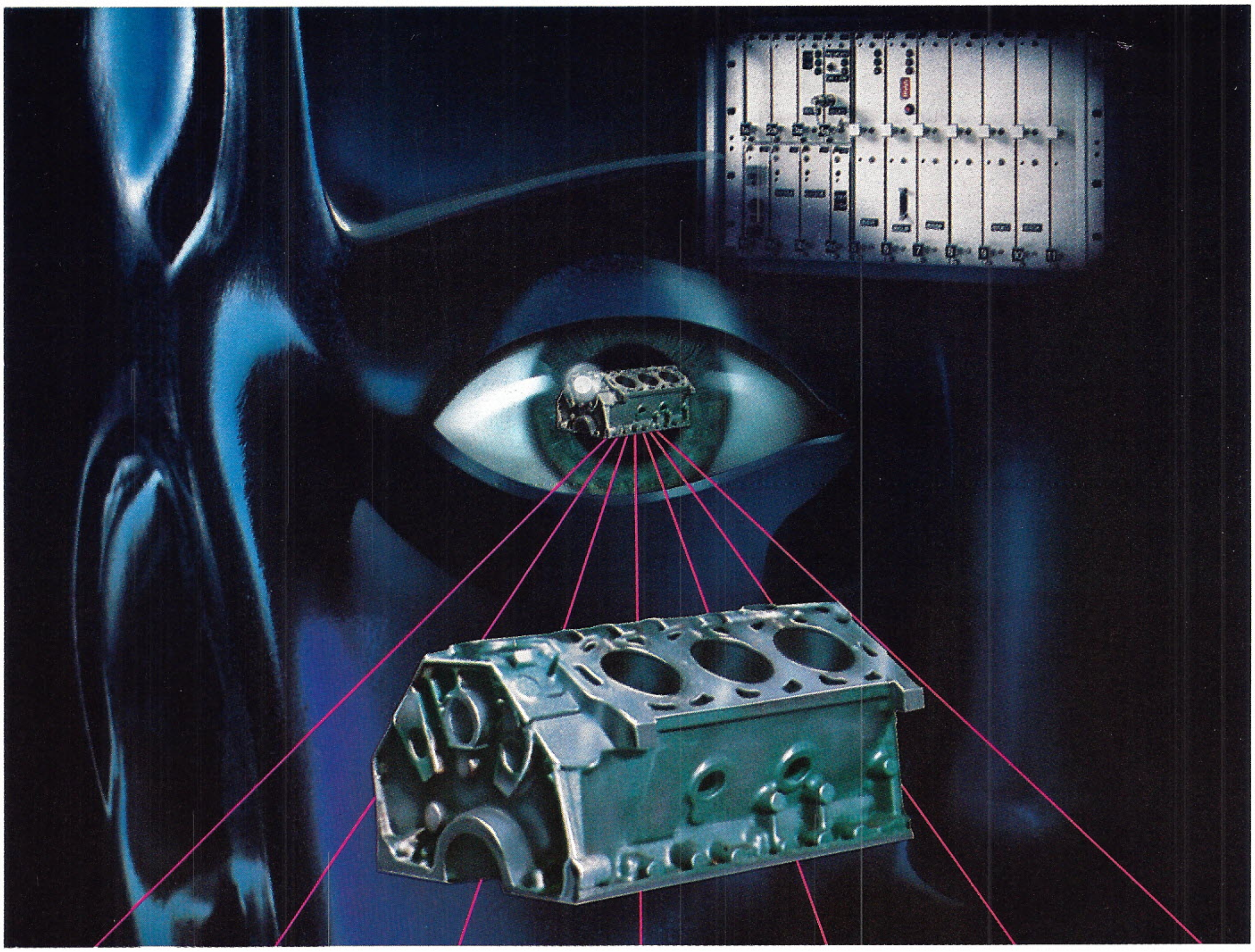
ROBOTICS ENGINEERING

THE JOURNAL OF INTELLIGENT MACHINES

Machine Vision Technology

Robotic Welding

Inside: Special Vision Technology Supplement!



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ROBOTICS ENGINEERING

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EDITORIAL

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DEPARTMENTS

About the cover: This month's cover photo, supplied by General Electric Company's Robotics and Vision Systems Dept., depicts the P60 arc welding robot using the MIG TRAK™ joint tracking system to simultaneously track and weld. The system employs laser light to locate and follow seams, even when they are moving due to part warpage during welding. See related article on page 8.

Editorial

The Vision Option

BY CARL HELMERS

We are to a great extent visually oriented beings; sight—and hearing—are popularly thought of as our most precious senses. The blind poet Milton and the deaf composer Beethoven both testified to this. Human vision is so complex a process that the use of machine vision in the service of automated engineering systems is just beginning. The technology is still very new, and major breakthroughs in this demanding field have been infrequent. Compared to sciences such as genetics and aeronautics, machine vision is only beginning to emerge from the Dark Ages. In this issue of *Robotics Engineering* appear several approaches to machine vision systems and their applications. Readers will also find in this issue a special supplement presenting the basics of what machine vision is, assessments by some of the industry leaders of the technology's present and future status, and a look at some real-world applications of the technology. Automated vision can, even at its present stage of development, provide more consistent and reliable information on an assembly fabrication or inspection line than could a human eye/brain endeavor.

The decision to buy and install a vision system or subsystem should be preceded by a careful analysis of the goals, the available capabilities of off-the-shelf modules, and the engineering tradeoffs expected. Not every need to sense an environment or a condition requires or is best served by the specialized capabilities of machine vision.

A vision system is inappropriate for a simple presence/absence determination of parts moving along the line of a conveyor belt, whether loaded manually or automatically. Such parts location might be better addressed by interruptive or reflective photosensors, proximity detectors, or even mechanical switches. A presence/absence detector might be used to cue the analysis process of the more elaborate vision systems that could then properly be used to extract more extensive two- or three-dimensional information about the part in the field of view. This more extensive analysis is the realm of vision systems and associated pattern recognition abilities.

The goals of vision system integration in the production environment are very application specific. One goal is to recognize objects in a production process. This identification procedure analyzes the image obtained and compares its characteristics to those stored in a pre-established database. One of the simplest implementations of identification is looking at a tag or label and reading the one- (bar code) or two- (OCR) dimensional character information on that tag.

The goal of inspection—verifying two- and three-dimensional characteristics—is an improvement in quality control. The message received by the system may be used to accept or reject an object and route it to the appropriate location. In more complex applications, the vision system may give manipulation parameters and approach trajectories to a robotic arm engineered to grasp the object. Other specialized applications include weld seam tracking and guidance techniques.

As with all adaptations and uses of new technology, the effective application of vision requires a great deal of understanding. Many potential vision applications demand custom engineering and are still too expensive to be practical. Vision technology is advancing and holds great promise, but the benefits and drawbacks of the vision option must be carefully considered. ■

Calendar

JUNE

2–5. VISION '86. Cobo Hall, Detroit, MI. Contact: VISION '86 Public Relations, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0777.

4–6. ROBEXS '86. Gilruth Recreation Center, NASA/Johnson Space Center, Houston, TX. Contact: Instrument Society of America, 67 Alexander Dr., PO Box 12277, Research Triangle Park, NC 27709, telephone (919) 549-8411.

5–6. Second Annual Workshop on Robotics and Expert Systems/ ROBEXS'86. Gilruth Center NASA/Johnson Space Center, Houston, TX. Contact: Deborah A. Poor, Instrument Society of America, 67 Alexander Dr., PO Box 12277, Research Triangle Park, NC 27709, telephone (919) 549-8411.

8–10. AI in an IBM World. Westin Hotel, Stamford, CT. Contact: New Science Associates, 46 Hunt Terrace, Greenwich, CT 06831, telephone (203) 531-0050.

9–14. Advanced Problems in Equipment Maintenance. Bowling Green State University, Bowling Green, OH. Contact: Dr. Richard A. Kruppa, Director, College of Technology, Bowling Green State University, Bowling Green, OH 43403, telephone (419) 372-2439.

15–21. Engineering Update Series in Electro-Optics. Tufts University, Medford, MA. Contact: Tufts/ SPIE, Continuing Education, Tufts University, 112 Packard Ave., Medford, MA 02155, telephone (617) 381-3562 (registration), (617) 381-3136 (technical information).

16–20. Teaching Introduction to Robotics and Work Cell Programming Courses. Conference Center, Piedmont Technical College, Greenwood, SC. Contact: Bobbie Peterson, Continuing Education Division, Piedmont Technical College, Emerald Rd., PO Drawer 1467, Greenwood, SC 29648, telephone (803) 223-8357, ext. 342. (To bé repeated **7–11 July, 14–18 July**, and **11–15 August**).

17–18. Robotic End Effectors: Design and Applications. Detroit, MI. Contact: Diane M. Korona, Program Administrator, Special Programs Division, Robotics International of SME, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-0039.

23–26. Automatic Test Equipment Conference and Exposition. Boston, MA. Contact: Technical Activities Department, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1080.

23–27. Robot Design and Control. Massachusetts Institute of Technology, Cambridge, MA. Contact: Office of the Summer Session, Room E19-356, Massachusetts Institute of Technology, Cambridge, MA 02139, telephone (617) 253-2101.

24–26. Advanced Manufacturing Systems. McCormick Place, Chicago, IL. Contact: Cahners Exposition Group, 1350 E. Touhy Ave., PO Box 5060, Des Plaines, IL 60017-5060, telephone (312) 299-9311.

25–27. Twin Cities Tool & Manufacturing Engineering Conference and Exposition. St. Paul Civic Center Arena, St. Paul, MN. Contact: Public Relations Department, Society of Manufacturing Engineers, One SME Dr., Dearborn, MI 48121, telephone (313) 271-0777.

25–28. CAD and Robotics in Architecture and Construction. Contact: Viviane Bernadac, International Institute of Robotics and Artificial Intelligence of Marseille/ CMCI, 2, Rue Henri Barbusse, 13241 Marseille CEDEX 1, France, telephone (91) 91.36.72.

27. Flexible Manufacturing Systems Workcell Workshop. St. Paul Civic Center, St. Paul, MN. Contact: Society of Manufacturing Engineers, Technical Activities Dept., PO Box 930, One SME Dr., Dearborn, MI 48121, telephone (313) 271-1080.

29–2 July. 23rd ACM/IEEE Design Automation Conference. Las Vegas Hilton, Las Vegas, NV. Contact: 23rd Design Automation Conference, 7366 Old Mill Trail, Boulder, CO 80301, telephone (303) 530-4333.

JULY

14–18. Computer Vision and Image Processing. Chrysler Center for Continuing Engineering Education, University of Michigan, Ann Arbor, MI. Contact: Engineering Summer Conferences, 200 Chrysler Center—North Campus, the University of Michigan, Ann Arbor, MI 48109, telephone (313) 764-8490.

AUGUST

11–13. Third International Robotic Systems Education and Training Conference. Plymouth Hilton Inn, Plymouth, MI. Contact: Mary Dombrowski, SME Special Programs Division, Society of Manufacturing Engineers, One SME Dr., PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500, ext. 392.

Letters

*The article on Karel (*Robotics Age, *September 1985) incorrectly identifies AML as a "first-generation" robot language, characterized by "simple control structures," "integer arithmetic," and other limitations.*

In fact, AML had complete control structures (IF.THEN.ELSE, WHILE.DO, REPEAT.UNTIL, BRANCH), varied data types with full arithmetic support, user interrupt handling, process control support, full I/O, and secondary storage. These features existed in experimental versions of AML as early as 1978, were applied inside IBM's manufacturing plants that year, were test marketed in 1981, and were announced in 1982.

Even more advanced experimental work on AML has been reported in numerous technical articles, including its enhancement for vision applications, dating back to about 1980. The latest experimental version of AML includes features for both conventional and object-oriented programming. Researchers are exploring its use for robotics, vision, numerical control machining, workstation control, and even computer aided design. This system is implemented in C and has been ported to IBM-370, Motorola 68000, and IBM PC hardware, running under CMS, XENIX (trademark of Microsoft), UNIX (trademark of AT&T), and DOS.

If one is counting language generations, then this version of AML should probably be considered the world's first third-generation robot language.

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Practical Optics for Machine Vision Systems

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A proper understanding of the characteristics and limitations of lenses, which are the most critical optical components of a machine vision system, can often produce dramatic improvements in system performance.

Imaging is the most obvious application. Here, the object under test is mapped point by point onto the active area of the camera. In a white light illumination source, on the other hand, condensing lenses determine the amount of radiation collected from the filament, and the uniformity with which it is projected. Structured light sources use lenses to shape the characteristics of the projected pattern down to the microscopic level.

All three applications are best understood as imaging applications, for even when collecting radiation from a white light filament the question that must be answered is where to place the image of the filament. If the engineer always chooses to collimate or place the image at infinity, the results can be far less than optimum.

IDEAL GEOMETRIC IMAGING

Consider the simplified illustration of the object-lens-image relationship as shown in Figure 1, where the object is modeled as an infinite number of infinitesimal point sources, each of which uniformly radiates light rays through a hemisphere. The purpose of the imaging lens is to collect a diverging cone of rays defined by the aperture of the lens (a subset of that hemisphere of radiation) from each point in the object plane and bend them so that they converge back to a point in the image plane. The positions of the target and image planes are related through the classic lens equations:

$$\frac{1}{L} + \frac{1}{L'} = \frac{1}{F} \tag{1}$$

and

$$M = \frac{L'}{L} \tag{2}$$

where F is the focal length of the lens, and M is the object-to-image magnification.

Each object point is thus mapped to a corresponding image point, and the object is almost completely reconstructed there. However, even if the lens produces a perfectly accurate mapping, there is one significant difference between the object and the image: each point in the image plane does not reradiate through an entire hemisphere, but instead radiates only through the cone defined by the aperture of the lens. (For a glossary of terms, see sidebar on page 6.)

APERTURES

Lens apertures are commonly disregarded, perhaps because they are often implicit in the outer diameter of the lens itself. But if the lens aperture, and prior or subsequent images of that aperture, are not taken into account when laying out an optical system, severe difficulties can arise. For example, in the lens system shown in Figure 2a, three lenses are used to successively relay an image; the image from the first lens is used as the object for the second lens, and the image from the sec-

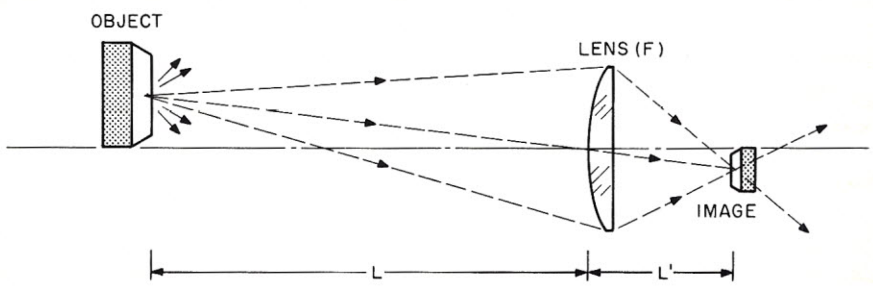

Figure 1. With an imaging lens, an object is modeled as an infinite number of infinitesimal point sources, each of which uniformly radiates light rays through a hemisphere.

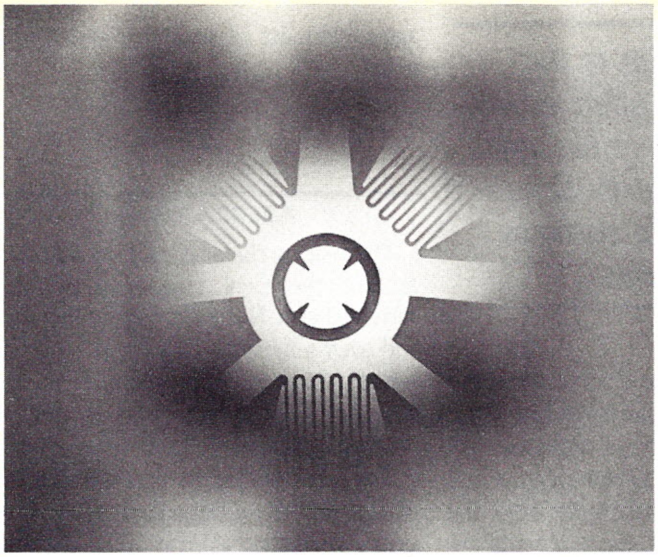

Photo 1. In this system, a single exterior lens is used to relay an image into the objective of a 35mm camera. The omission of a field lens produces an intensity drop-off so severe that the outer portions of the image are completely truncated and some of the relay lens mount is visible.

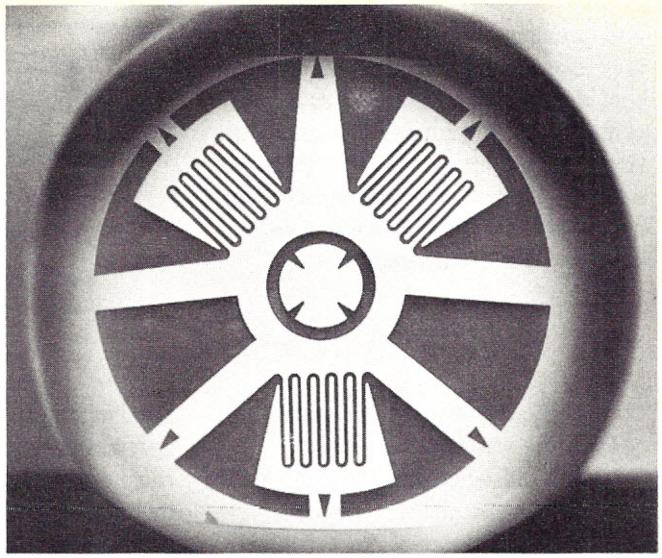

Photo 2. The system is the same as that shown in Photo 1, except for the inclusion of a field lens that more than triples the available field of view.

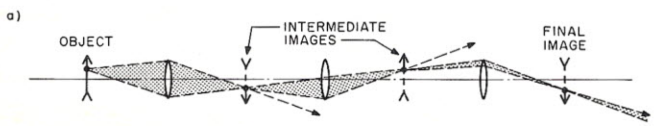

Figure 2a. In an improperly designed relay system, the cone of rays the first lens provides for the second lens is not directed toward the center of that lens, and the cone is more and more truncated for each successive lens. The final image suffers from a severe drop-off in intensity for off-axis object points.

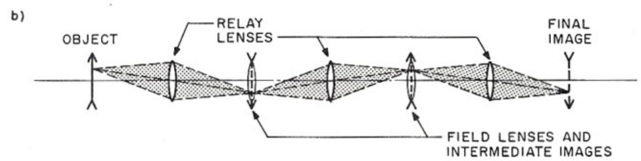

Figure 2b. One solution to the relay lens problem of Figure 2a is to place a field lens at each intermediate image.

ond as the object for the third. The shaded area indicates the cone of rays each lens accepts for an off-axis target point, and since any target point radiates through a hemisphere, the aperture of the first lens is completely filled. However, the center of the cone of rays the first lens provides for the second is not directed toward the center of the lens, and the cone for that target point is truncated, and then further truncated at each successive lens that might be part of such a system, resulting in a final image that exhibits a severe drop-off in intensity for off-axis target points (Photo 1).

The solution to the relay lens problem is to place a **field** lens at each of the intermediate images, as in Figure 2b. Since each field lens is located directly on top of an object image ($L=0$) it has no effect there ($L' = 0$ and $M = 1$). Its single purpose is to bend the central ray of the cone of rays emerging from the target point so that it always passes through the center of the next relay lens, i.e., it images the aperture of one relay lend onto the aperture of the next (Photo 2).

The user should remember that for the object, the object image, and each intermediate object image, there is always an associated aperture image—there should be only one physical aperture in any system—that defines the cone of rays through which any point in each object image will radiate. Each object image and its associated aperture images are sufficient to define fully the radiating characteristics of that image space. The system shown in Figure 2b works because care has been taken to ensure that not only are the object images relayed, but that each aperture image is also relayed to the next image space.

Figure 3 is identical to Figure 1, with the exception that the aperture stop is a physical aperture placed between the object and the lens. Here the aperture stop and the entrance pupil are one and the same, and the refracting surfaces of the lens form an image of the stop in addition to an image of the object. This stop image is the exit pupil; it defines the limits of the cone of rays for each object image point, and its position and magnification can be computed by substituting L_A and L'_A in place of L and L′ in Equations 1 and 2.

DIFFRACTION

Diffraction is fundamental to the propagation of electromagnetic radiation, and results in a characteristic spreading of energy beyond the bounds predicted by a simple geometric imaging model. It is most readily apparent at the microscopic level when the size of the optical distribution is on the order of the wavelength of light (for instance, near a focused spot), and can often be ignored for larger distributions.

For imaging, this means the light collected from a single point in the object is focused to a finite, rather than an infinitesimal, spot in the image. If the radiation from the object point fills the lens

aperture uniformly, and the lens aperture is circular and unobstructed, the resultant spot distribution will appear as a bright central disk surrounded by concentric rings. According to the wave theory of light, the central disk contains 83.8 percent of the total energy in the spot distribution, and has a diameter of

$$D_s = 2.44\,\lambda \frac{L'}{D} \qquad (3)$$

where

D_s is the diameter of the spot;
λ is the wavelength;
L' is the distance from the exit pupil to the image; and
D is the diameter of the exit pupil.

"Lens design is the science—and often art—of balancing positive and negative contributions from multiple surfaces and elements..."

The most immediate effect of diffraction is to limit the information bandwidth of the system. In the target image, diffraction will cause adjacent points to blur together and therefore be unresolved, one from the other. To be resolved, the centers of image spots must be separated by approximately

$$\frac{D_s}{2}.$$

ABERRATIONS

The imaging characteristics just described are for the ideal case of a perfectly corrected lens. No lens is perfect, however, and even a perfectly fabricated spherical surface will not redirect the cone of rays from a target point back to an infinitesimal point in the image. Simple geometric theory predicts that the rays will miss the perfect point by a finite error referred to as the **geometric aberration** of the lens. The result is a slightly blurred or repositioned spot.

Lens design is the science—and often art—of balancing positive and negative contributions from multiple surfaces and elements to minimize that error. When the designer achieves a configuration in which the contribution of the geometric aberrations to the spot blur is far less than that of diffraction, the lens is referred to as **diffraction limited.**

Chromatic aberration, which arises because the index of refraction of glass, and hence the focal length of a lens, varies with the wavelength of light. Chromatic effects are a problem only in lenses that must pass a broad spectral band of optical radiation (white light), producing, in effect, an image that is separated into planes of distinct color; in any given plane, all colors but one are out of focus.

An **achromat** is a two-element lens in which two dissimilar glasses are used to match the focal length at two wavelengths (red and blue). An achromatized lens will usually perform well throughout the visible portion of the spectrum. It is not uncommon for an achromatized lens to work properly in the near-infrared as well, although it is usually too much to ask it to operate simultaneously throughout the visible and the near-infrared. If near-infrared performance is desired, the blue and green portions of the spectrum should be blocked.

Monochromatic aberrations arise even in narrowband radiation, such as lasers, and can be grouped in terms of function.

- Category 1 includes those that spread or blur the image spot, producing a loss of definition or sharpness in the image, and

Selected Glossary of Optics Terminology

The following is an abbreviated list of important terms to consider when selecting, specifying, or using a lens:

Effective focal length (EFL): The fundamental measure of the imaging power of the lens, and the parameter used for F in Equation 1.

Front and back focal lengths (FFL or BFL): The physical distances from the outermost element (or edge of the lens barrel) to the focal points on the front and back of the lens. They might be more appropriately called working distances, since they are not the focal length that determines the imaging power of the lens.

F-number (F/No.): The ratio of the focal length to the aperture diameter of the lens. On most commercial lenses it is the F/No. that is listed on the aperture adjustment, not the actual aperture diameter.

Field of view: The maximum target diameter within which geometric aberrations have been properly corrected. The field of view can also be defined in image space, such as the active area of a camera tube, or, as the term is used in astronomy, it can be defined by means of the maximum apparent angle of a distant object.

Aperture stop: The physical aperture that limits the cone of rays accepted by the lens. In practice, to prevent scattering and reduced image contrast, the edges of the glass within the lens should never be allowed to define the aperture of the system. There should be only one physical aperture in any system and its edges should be distinct and well-defined. The purist will prefer a knife-edge, but in all but the most extreme circumstances a thin, unrounded aperture edge will do nicely. All other surfaces should be enlarged enough to pass the cones of rays defined by the aperture stop.

Entrance pupil: The image of the stop (assuming the aperture stop is buried within the lens) on the entrance side of the lens. If the stop is in fact located on the entrance side of the lens, then the aperture stop and the entrance pupil are one and the same.

Exit pupil: Identical to the entrance pupil, but on the exit side of the lens.

Paraxial: Paraxial ray trace equations are derived from the mathematical limit as all ray angles and positions approach zero relative to the optic axis. Also referred to as "first order optics," they are essentially the first term in a series expansion. and they represent the ideal, linear lens.

• Category 2 includes those that merely shift the mean position of the spot, distorting the shape of the image but not limiting the information contained within it.

Spherical aberration, **coma**, and **astigmatism** fall into the first category. When combined with the effects of diffraction, they limit the transverse resolution of the lens. Spherical aberration is an optical defect of refracting and reflecting spherical surfaces in which light rays from one axial point, incident on the surface at different distances from the optical axis, do not come to a common focus; coma is a diffuse pear-shaped image of a point source; and astigmatism refers to a refractive defect of a lens that prevents focusing of sharp, distinct images. As one opens the aperture of a lens, these aberrations all increase steadily, while, as per Equation 3, diffraction effects decrease, and in most lens designs the highest resolution is achieved at two or three stop positions short of the widest aperture.

Curvature of field produces an image plane of best focus that is literally curved, resulting in an image that might be sharply focused at the center but progressively blurred near the edges. Technically, curvature of field is a longitudinal shift in the spot position and is classified as a Category 2 aberration, but since it results in defocus in portions of the field of view, its effects more resemble those of Category 1.

Distortion is nonlinearity in the transverse mapping from the target plane to the image plane, and its effects are strictly those of Category 2. In television lenses and other systems tailored for human viewing it is usually assumed at the design stage that distortion (the fisheye effect) is less detrimental than blurring and defocus, and distortion criteria are often relaxed. Fortunately, geometric calibration grids can be used to map such distortions, and compensation can be achieved in the system software.

J.L. Doty, who holds a Ph.D. in electrical engineering, is Product Line Manager at Newport Corporation.

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Excellent	Good	Fair

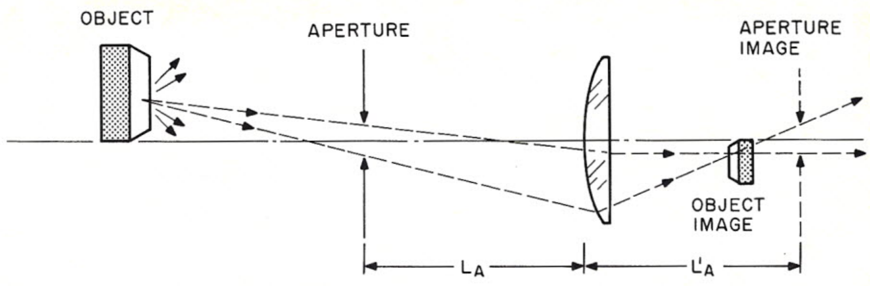

Figure 3. Similar in most respects to Figure 1, in this arrangement the aperture stop is a physical aperture placed between the object and the lens. With the aperture stop and the entrance pupil one and the same, the refracting surfaces of the lens form an image of the stop as well as an image of the object.

Optical Seam Trackers: Tough Requirements for Design and Laser Safety

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General Electric Company
Robotics and Vision Systems Department
PO Box 17500
Orlando, FL 32860-7500

One of the hottest competitions in the robotics industry today exists in the area of seam trackers for welding robots. It is an accepted fact that robots can weld much faster and more consistently than human welders. Once the exact path and welding parameters are programmed into the robot controller, the robot can repeat the operation night and day for months at a time.

In fact, a robot could make *perfect* welds for months and months were it not for another accepted fact: parts vary. The parts being welded vary slightly in shape because tools wear, spring-back varies with batches of material, parts are accidentally dented, assemblies are not always aligned perfectly in the fixture, and warpage during welding is not consistent.

To achieve maximum quality and efficiency, the robot should be able to find and follow the actual seam location in real time on every part. The accurate and reliable achievement of this goal took years to perfect, and with it brought on a new consideration in the welding industry—laser safety.

SEAM TRACKING SENSOR TECHNOLOGY

Although the largest installed base for seam tracking is through-the-arc sensors, the market is shifting rapidly toward optical sensors. Optical sensors operate at higher speeds and can track into the arc-on point. The concept is simple: look at the surface of the part directly in front of the torch, locate the geometry that has been predefined as the joint to be welded, and direct the robot's path along it. (The feature extraction and tracking control algorithms will not be discussed here because "it's only software.")

The problem lies in forming a usable image of the joint on varying surfaces within an inch of a MIG welding arc. Imagine looking at a surface that ranges from shiny new steel to dull, rusty, or even black oxide finish and trying to locate a joint that may be the same size as the scratches left by the local delivery truck. Once you have mastered that, strike an arc 1 in. from that point with a 650 amp MIG welding power supply. You now have a light source that is brighter than the sun, containing all visible and many invisible wavelengths, and being modulated at random frequencies. Add to that red hot spatter flying through the field of view and smoke billowing in all directions. The smoke not only contaminates the optics but also scatters additional arc light toward the light detector. Protecting the optics from spatter and smoke is relatively easy. Baffles, disposable windows, and cover gas can be designed to block any direct path to the optics. Finding the joint is another matter.

Seeing the variety of surface finishes through the harsh lighting conditions of welding has been the major stumbling block in developing a factory ready optical seam tracker. The simplest system is just a camera that uses the arc light to locate a gap to be filled by welding. Arc illuminated camera imaging would be a fine system if the illumination did not vary too much (it does) and if tracking didn't begin until after welding has begun (usually not true).

The next step is to add structured light to the camera image to track independently of the arc. Most seam trackers use a laser in order to distinguish the tracker's light from the arc light. A laser produces coherent monochromatic light of extremely high intensity. Even a low-power laser such as a 1 milliwatt continuous wave Helium-Neon (1 mW cw HeNe) produces light 130 times brighter than the sun including all of the sun's wavelengths, or 200,000 times brighter at the laser's specific wavelength. Since the laser produces only one wavelength of light, a spectral filter can be used to block all other wavelengths, thus isolating the sensor's structured light pattern from the arc light. For example, a bandpass interference filter with a bandwidth of 1 nanometer will transmit 30 percent of the specified wavelength ± 0.5 nanometers and less than 0.0001 percent at other wavelengths. Since the arc light is spread over the entire spectrum, the filter reduces the arc light transmitted by approximately 1000:1.

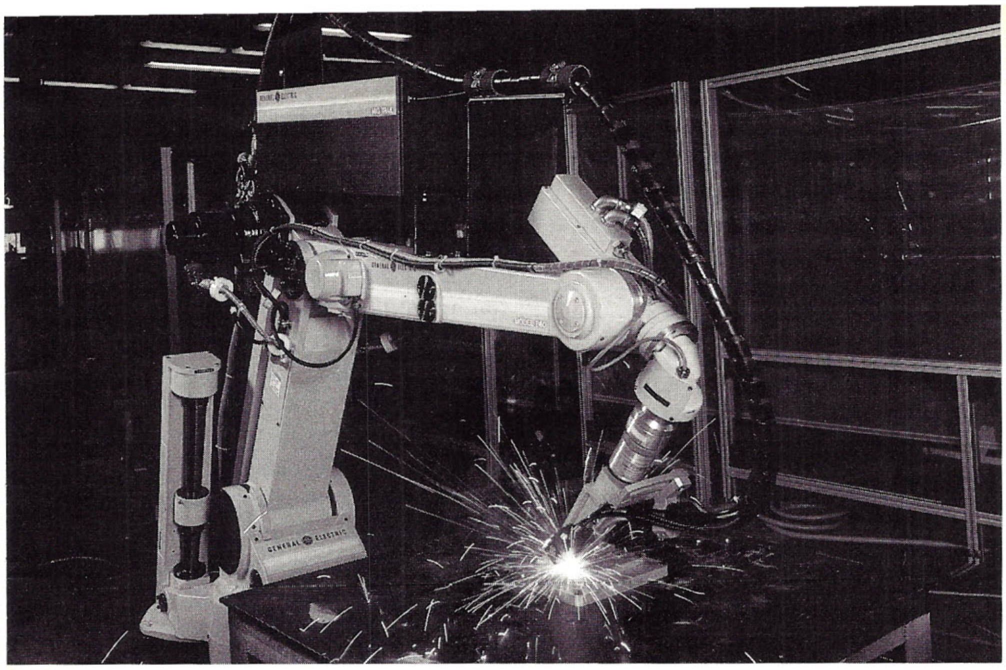

Photo 1. The arc produced by a 650 amp MIG welding power supply creates a light source that is brighter than the sun, containing all visible and many invisible wavelengths, and being modulated at random frequencies. Shown is a General Electric arc welding robot with laser-guided seam tracking capabilities.

The use of a laser as the light source also produces a much more sharply focused image due to the total lack of chromatic aberration and the ideal condition of focusing a collimated Gaussian beam. The laser stripe or other pattern is often projected from an angle with respect to the line of sight of the objective to provide triangulation data used to calculate the height profile of the joint. This approach is required because the joint geometry is usually not a simple gap but a three-dimensional overlapping of parts where a certain inside or outside corner is to be welded. Accordingly, the requirement for laser power is increased because only diffuse reflection reaches the objective; any specular reflection goes on past the objective.

The use of structured light from a laser with a camera to locate the joint is a common technique in the industry, and it represents a major improvement over simple cameras. It does, however, have drawbacks. Bandpass filtering to reject the arc from the image has a definite limit, and surface reflectivity varies greatly. A solid-state camera looking at a stripe of laser light on the part is also looking at one to two square inches of arc light, which may result in the collection of enough light in the field of view to blind the sensor. One solution is to move away from the arc, since intensity decreases at $1/\text{distance}^2$, but then tracking accuracy is decreased. A second option is to add more laser power to overcome the increasing arc light.

A similar problem exists in the variation in surface reflectivity. A perfect surface to track would be white paper, which produces a uniform bright reflection over a wide viewing angle. Looking at metal is not that easy. Shiny steel angled away from the detector or dark surfaces like black oxide steel might return 1 percent of the white paper light level, and shiny steel angled for specular reflection might return 1000 percent of the white paper light level. Again, the laser power is increased to be able to see surfaces causing a low return. With the laser power sufficient to see a shiny surface angled away from the detector, the introduction of a sandblasted surface or changing the part angle to cause specular reflection will completely blind the camera. Automatic gain controls are useless in this application because they adjust the gain of the whole frame and these variations usually occur within a frame. Some of the present camera-based systems project 5 to 40 mW of laser power to overcome the arc and surface variations. This power level raises concerns over eye safety and protection.

More recent developments in optical seam trackers include special tricks that improve the image without increasing laser power. Some products project a small scanned pattern instead of a large fixed pattern in order to increase power density while reducing the total power level. Decreasing the field of view reduces the amount of arc light that must be overcome. Special detectors are being developed for lower light levels and more dynamic range. Another complication that has been overcome by a few seam trackers is multiple reflections. The structured light pattern reflects around inside the joint and produces false images. The optics need to block secondary reflections and pass only the original laser pattern. Even though these improved sensors have greatly reduced laser power (as low as 0.95 mW total radiated power), laser products can be dangerous if improperly designed or misused.

LASER SAFETY

The laser is a misunderstood and often feared device in industry. It has the power to blind, it can burn through steel, or it can be just a bright monochromatic light. The danger of a specific laser depends on the wavelength, exposure duration, and power level. For example, the CO_2 and the Nd:YAG lasers are commonly used in the cutting and welding industry. If two such lasers are focused through a 5 in. focal length lens for cutting, the beams would diverge beyond the focal point. Since the power density decreases with distance, each laser will have a distance at which the beam no longer presents an eye hazard. According to R. James Rockwell Jr. in his article "Ensuring Safety in Laser Robotics," a 1000 W cw CO_2 laser should be a minimal hazard beyond 18.5 ft but a 300 W cw Nd:YAG would constitute a hazard at distances less than 213 ft. The reason for this is the CO_2 wavelength does not penetrate the cornea of the eye; the only danger is that of tissue damage. The Nd:YAG is focused on the retina of the eye and is invisible; therefore, the eye's natural aversion reaction to bright light does not come into play, and eye damage can easily occur.

There are two governing organizations for laser safety: one for safe working environments and the other for safe products. The Occupational Safety and Health Administration (OSHA) controls the safe exposure level in the work place. The Center for Devices and Radiological Health (CDRH), a part of the United States Food and Drug Administration, controls power level classification and safety features of laser products. Its regulations are the Code of Federal Regulations, Title 21, Part 1040, "Performance Standards for Light-Emitting Products" (21 CFR 1040). Since both organizations agree on

Table 1
Classification and Safety Requirements for Visible and Near-IR Lasers

Class and Wavelength	Maximum Power and Potential Damage	Selected Safety Features (summarized from 21 CFR 1040)
All Classes	n/a	Certification label Protective housing
Class I Visible and near-IR (400-1400 nm)	<0.0004 mW cw <0.0000004 J pulsed Minimal hazard	No additional requirements
Class II Visible only (400-710 nm)	<1mW cw <0.001 J pulsed Eye hazard if viewed for extended period	"CAUTION" warning logotype Aperture label Visual or audible warning Beam attenuator
Class IIIa Visible only (400-710 nm)	1-5 mW cw when <2.5 mW/cm² Not pulsed Eye hazard if viewed for >0.25 sec.	"DANGER" warning logotype Aperture label Visual or audible warning Beam attenuator
Class IIIb Visible and near-IR (400-1400 nm)	5-500 mW cw <10 J/cm² pulsed Immediate eye hazard Potential skin hazard	"DANGER" warning logotype Aperture label Visual or audible warning with delayed emission Keyswitch retained in ON position Remote control connector Beam attenuator
Class IV Visible and near-IR (400-1400 nm)	>500 mW cw >10 J/cm² pulsed Immediate eye hazard Immediate skin hazard Potential fire hazard	"DANGER" warning logotype Aperture label Visual or audible warning with delayed emission Keyswitch retained in ON position Remote control connector Beam attenuator Manual reset after power interruption

the definitions of laser safety classifications and the required safety features for products, and since OSHA enforces workplace safety, which is the buyer's duty, we will concentrate here on product safety as defined in 21 CFR 1040.

Classes of Lasers. Existing optical seam trackers typically use two types of lasers: Helium-Neon (HeNe), which operates in the visible red region, and diode lasers, which operate in the invisible, near-infrared region. The laser can usually be considered a point source, meaning that it can be focused very sharply on the retina. The retina uses only about 5 percent of incident light for vision; the remainder is absorbed and converted to heat. Excessive incident radiation from lasers will cause permanent retinal burns.

According to an article published in *Laser Safety,* Class I lasers as defined by CDRH, should not produce an eye hazard under normal operating conditions. Above Class I are two classes specifically for visible lasers: Class II low-power and Class IIIa medium-power lasers. These are limited to visible wavelengths that can cause eye damage, but the normal human aversion response to extremely bright light (blinking and turning away) takes less than 0.25 sec., fast enough to protect the retina from permanent damage. This involuntary reaction is, of course, useless for the near-infrared wavelengths the eye cannot see, increasing the hazard of these lasers. Class IIIb and Class IV lasers present much greater hazards because eye and even skin damage is instantaneous. Accordingly, some form of artificial protection is required.

Defining Laser Classes. The measurement of power and energy levels used to define the classes is performed in several ways. (See 21 CFR 1040 for exact procedures.) The light from visible lasers is measured through a 7 mm aperture at 20 cm from the point where the beam leaves the protective housing. This aperture approximates the size of the pupil of the eye in a fully dilated state. For devices where collecting optics (such as binoculars) may be used, the aperture size is increased to 80 mm.

For continuous wave lasers, the measurement is based on the amount of power in milliwatts that can be collected in the aperture. Measurement is more complex for pulsed or scanning lasers. Since the damage lasers can cause is primarily thermal, an extremely short pulse of high peak power can be safer than a low-power continuous beam because the total energy contained in it is less. Therefore, the limits for pulsed or scanning lasers are calculated using the peak power, pulse duration, and pulse frequency, and are expressed in

Laser-Guided Joint Tracking

General Electric's MIG TRAK™ joint tracking system, designed for robotic MIG welding, enables the robot to simultaneously track and weld at speeds of up to 100 in./min.

System components include a low-power (less than 1 mW) HeNe laser; a sensor that travels with the torch and modifies the programmed path in real time, making for one-pass operations; and a proprietary optical system that images the laser light on the weld joint being tracked. Reflected laser light is funneled through a fiber-optic bundle to intelligent image-processing circuits that translate the visual data into directional commands that guide the robot along the joint.

MIG TRAK can weld parts with dull, shiny, rusty, or oily surfaces without requiring special preparation such as sandblasting or chemical etching. It can handle all the major varieties of joints, including butt, v-prep butt, lap, and fillet. The system compensates for part warpage during welding by adjusting the robot's path to follow the moving seam.

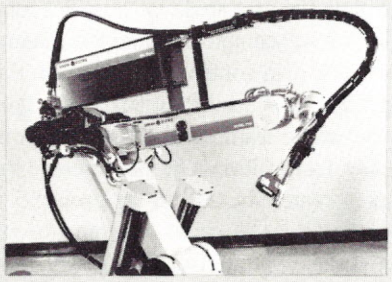

Photo 1. The MIG TRAK joint tracking system, shown mounted on GE's Model P60 welding robot, is designed for speedy, one-pass operations.

joules (J) or joules/cm². Examples of some of the classes, power limits, and required safety features for the lasers used in seam trackers are summarized in Table 1.

Safety Measures. The CDRH product safety regulations listed in 21 CFR 1040 describe in detail the function of each safety feature and list the exact wording of each label. The protective housing prevents access to laser radiation levels above those necessary for operation. The product can contain a laser source of a higher power rating and remain in the same class, however, if only specially trained personnel have access to it. Additional labeling and interlocks on the enclosure are nonetheless required.

All laser products must also have a permanently affixed label that indicates compliance with 21 CFR 1040 and the company's name and location. User documentation of laser products is required to include reproductions of the CDRH safety labels and information on the product's power level and classification. Instructions on safe operating procedures should be included in the user's manual.

The CDRH requires that a detailed report be filed on every new laser product giving information on the required product safety features, the company's assembly and quality control procedures, and user documentation. The CDRH will not allow shipment (or import) of the product until a satisfactory report is on file.

The preceding information is intended to serve as an introduction to the types of laser technology used in optical seam trackers, the associated safety concerns, and some of the requirements for that type of laser product. It is not meant to be a definitive reference for designing or using laser products; the 21 CFR 1040 and ANSI Z-136.1 are the guidelines that must be fully understood and followed to the letter.

FOR FURTHER READING

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The Miller MR-5 Welding Robot

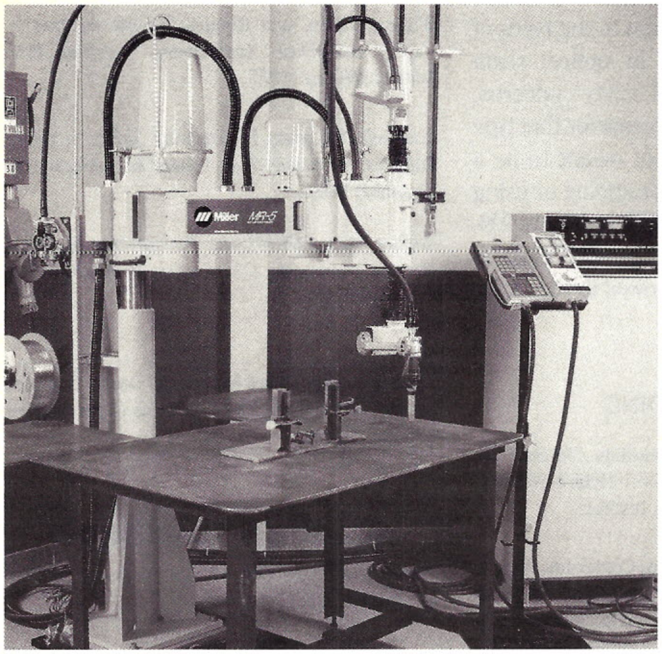

Photo 1. The MR-5 horizontally articulated robot is specifically designed to weld small pieces.

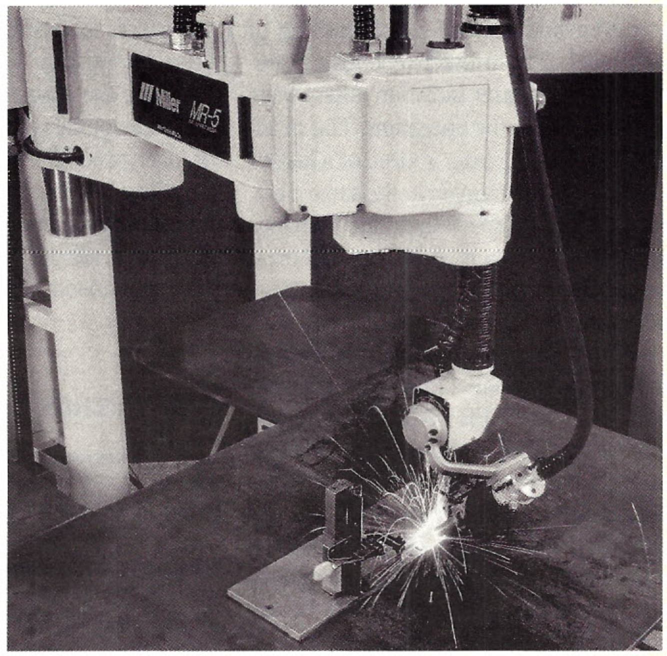

Photo 2. The robot is shown welding a rectifier mounting bracket that will be used with its welding power source.

Robotic welding machines, after getting off to a slower than predicted start, are beginning to find—and hold—an increasing number of positions in metalworking shops and auto body plants. While various interpretations of this new growth have been offered, most boil down to a response to overseas competition. Half of this response is based on simple economics. With the recent technological advances in both machinery and software, it has begun to prove more cost-efficient in the long run to weld with a robot that does not experience "bad days" or stop due to fatigue. The other half of the response also involves numbers—human numbers. Even before the introduction of robotic welding operations, the ranks of human welders had begun to shrink. Welding is hot, heavy, and hazardous work, and as the previous generation of master welders began to retire, a dwindling number of apprentices were there to replace them. Further, a properly designed and programmed robot can perform with an accuracy formerly reserved for humans with a considerable amount of training and hands-on experience.

The history of Miller Electric Mfg. Co. encapsulates the rise of robotic welding systems in this country. In 1929, Niels C. Miller perfected, in his basement, the first welding power source that could operate on 110 V single-phase power. His utility-type welder was first sold in the rural areas of Wisconsin. In 1981, Miller Electric began providing welding interfaces and power sources to the major robot manufacturers. In 1985, the firm signed an agreement with Osaka Transformer Company, whereby an exchange of certain products and technology took place between the two companies. A new product resulting from this agreement is the MR-5, a five-axis, horizontally articulated robot designed to weld a variety of small parts without elaborate fixturing and positioners.

THE ROBOT

The robot arm weighs 507 lb., including the base. Its axes are: "R," right to left and covering 235 degrees; "S," forward and back covering 155 degrees; "Z," up and down over 4-3/4 in.; "θ," torch head rotation covering 380 degrees; and "ϕ," torch angle or wrist rotation covering 260 degrees. Control of all five axes is independent and simultaneous via DC servo motors. The maximum axis speeds are: "R," 150 degrees/sec.; "S," 225 degrees/sec.; "Z," 11.8 in./sec.; "θ," 200 degrees/sec.; and "ϕ," 150 degrees/sec. The maximum allowable weight capacity is 6.5 lb., and repeatability is ± 0.004 in. Positional movements or movements between welds can be made at speeds of up to 150 degrees/sec. Welding speeds in a linear or circular interpolation are up to 137 in./min. Torch tip speed and torch angle always remain constant.

The welding power source, a Miller Deltaweld 450 (other machines can also be used), works in conjunction with the four-drive roll system for positive wire feed. The 350 amp air-cooled torch has a built-in touch sensor that automatically shuts the robot down if the torch strikes the fixture, the weldment, or other object.

THE CONTROLLER

The MR-5's memory capacity is 48 Kbytes, using the sequential memory

method. In the magnetic bubble memory, 3000 points or sequences can be stored (6000 more can be added by option). Since a typical program contains from 50 to 200 points, 255 programs can be stored, along with 255 jobs, which can contain several programs required to complete a particular task.

The operator and the robot communicate by way of a program module with an LCD display of numerical and alphabetical characters arranged in two rows of 20. The operation guides are in English and the weld parameters are in volts and inches per minute. Welding conditions include preflow time. Four different weaving functions can also be selected. Welding conditions modified while welding is in progress are automatically entered into memory.

The controller also provides a part count function the operator can call up on command and a self-diagnosis capability that is activated each time the robot is powered up. Checks are made of connections between the control unit and the program module, the welding power supply interface and control unit, the circuits of the control unit, the program module and welding power supply interface, and the connection between the robot and the main unit.

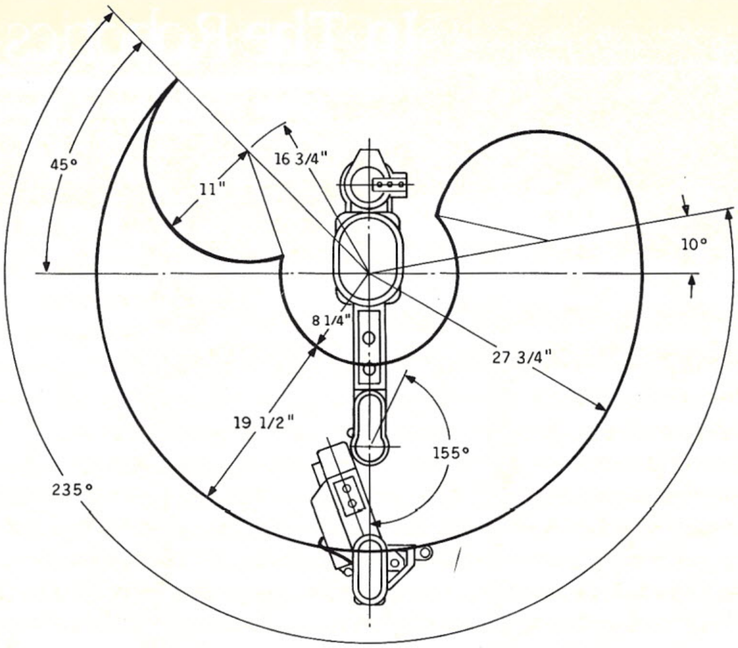

Figure 1. Control of the robot's five axes is independent and simultaneous, via DC servo motors.

OPERATION

When a robot is not actually welding, analog channels that control welding power source output and wire feed drive motors need to have some minimum value reference signals. If these signals are not preset, when the weld command is given the power source and the wire feed motor must ramp up from zero to the desired welding parameters and the result is poor weld starts. The MR-5 allows the operator to preload the analog channels with arc volts and wire feed speed, facilitating improved starts.

Another area of concern in welding operations is that not all material to be welded is as clean as might be desired. Dirty, rusty, and poorly grounded parts do not make good electrical conductors, and when the robot tries to begin welding such conditions can cause arc initiation to fail. Unfortunately, cleaning the materials prior to welding is impractical from the standpoints of time and economics. The MR-5 addresses this problem by attempting to start after an initial failure. When the start is unsuccessful, the robot retracts wire and tries again. If no start is achieved on the fourth attempt, a weld alarm is displayed.

After successful completion of a weld, most robots run through a wire stick procedure to ascertain that the welding wire is not frozen in the weld bead, as robot movement with a stuck wire can damage the gun or the torch. The wire can often be freed simply by pulsing the contactor of the welding power source, and the operator will not have to cut the wire and manually move the robot arm away from its work to a safe area for a restart. The MR-5's controller begins its check for wire stick with a low-voltage pulse. A frozen wire will send current through the weld secondary and be detected. The secondary is pulsed again at a higher voltage to burn the wire free, and once more at yet a higher voltage. Should three attempts fail to free the wire, a weld alarm is generated. The procedure takes only milliseconds, and is conducted in the presence of shielding gas. At present, 0.030 in., 0.035 in., 0.045 in., and 1/16 in. mild steel and stainless wires can be used. Packages that will allow pulsed gas metal arc welding on aluminum and other metals are under consideration.

The MR-5's work envelope can be divided into six stations, which means that up to six operators can work on six different parts with the same robot. When the operator is ready (part in place), he presses the start button on the appropriate module. The robot places the request on a first-come, first-served basis. Each start module is provided with emergency stop capabilities, as is the welding gun.

CONCLUSION

To make the MR-5 within the reach of the smaller shops, it is sold as a system that includes the robot, controller, welding interface, welding power source, wire feed drive equipment, outlet cables, welding torch, and gas control/current sense box. The buyer provides the primary cable, weld cable, welding wire, and shielding gas. Personnel support is offered by a team composed of welding engineers, electrical engineers, and technicians whose job it is to integrate robotic welding operations into the shops of 1986 as smoothly as Niels Miller's customers did his utility welder in 1929.

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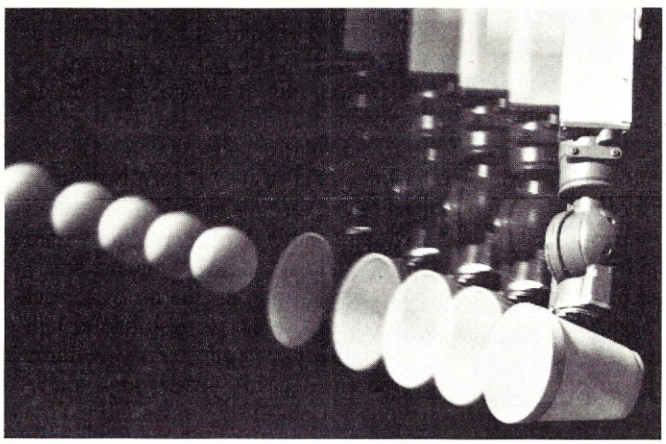
Edited by Stephanie vL Henkel

SCIENCE & TECHNOLOGY

Researchers at the **National Bureau of Standards** are testing a prototype computing device for machine vision systems that can perform approximately 450 million 8-bit operations per second, making it suitable for real-time image processing. The Pipelined Image Processing Engine (PIPE®) is the invention of Dr. Ernest Kent of the NBS, which has applied for a patent; the prototype was built by Digital/Analog Design Associates, Inc., of New York City. Even though highly specialized machines exist that can perform more calculations than PIPE, the NBS says, none can perform the continuous, frame after frame calculations necessary to analyze a constant video signal in a rapidly changing situation. Other features include a multiple instruction stream, multiple data-stream facility that allows PIPE to perform different types of analysis on the same video frame, depending on the nature of each point.



In a project designed to allow robots to plan and act in a dynamic and changing world, researchers at **AT&T Bell Laboratories** in Murray Hill and Holmdel, New Jersey are teaching robots to respond to spoken commands and to catch Ping-Pong balls on the first bounce. The voice-activated robot in the Murray Hill lab moves objects around on a table under the direction of its designers. It understands a 51-word vocabulary and is equipped with an ultrasonic rangefinder that permits it to find the correct object. In Holmdel, the ball-catching robotic system includes two pairs of TV cameras that monitor the ball's half-second flight and specially designed high-speed vision chips that process the ball's image as it is generated. A microprocessor computes the trajectory and relays the data to a robot controller that moves the arm into position to catch the ball in a cup. Both projects are expected to lead to real-world industrial applications.

Under an $800,000 contract from the **U.S. Air Force**, **General Electric** has undertaken the development of a prototype expert system designed to assist maintenance personnel in diagnosing jet engine malfunctions. The software is expected also to be able to determine exactly when engine parts should be replaced. Since there is no practical way to monitor the condition of parts buried within a jet engine (on-board sensors pose maintenance problems themselves and are kept to a minimum), Air Force mechanics are instructed to replace certain critical components after specified intervals. This approach means good parts are routinely pulled and replaced along with bad ones. The expert system will be able to analyze data available from various sources and suggest appropriate preventive maintenance or corrective actions.

Researchers at the National Bureau of Standards have demonstrated a laboratory system that could be the basis of an in-process check on the surface roughness of workpieces during machining. Such a monitor could be used to detect worn or damaged tools in an automated machining center *before* they begin to produce unacceptable parts. The NBS probe transmits ultrasound from a specially designed nozzle down the stream of coolant fluid and measures the amount of sound reflected back upstream. The proportion of reflected sound indicates the roughness of the workpiece's surface. Laboratory testing has shown that the system can measure a broad range of surface finishes at resolutions approaching 25 μin. on stationary parts. Acceptable results are also obtained when measuring curved surfaces rotating at up to 1000 ft/min. surface speed.

MARKET RESEARCH

Neither culture nor work ethic, but "mechatronics" best explains the reason the Japanese are currently out-competing the U.S. in many world markets, according to **Gerardo Beni**, co-director of the **Center of Robotic Systems in Microelectronics** at UC Santa Barbara, California. Mechatronics, a blending of mechanical and electronic design, has come to mean the science of designing and building precision, computer-controlled machinery, a blending of mechanical and electronic design. The Japanese have been building high quality products at a low price by coming up with innovative designs for the products and, in addition, developing the factory machinery required to make the product components. These engineers were trained at university departments of precision engineering, which differ from U.S. ME departments in stressing design, rather than analysis, of mechanical systems. Because

mechatronics involves simpler and more commonplace devices, it is not considered so glamorous as robotics, but trying to build robots before mastering the art of efficiently designing and manufacturing simpler computer-controlled machines is putting the cart before the horse, Beni says.

Unions are widely accused of opposing automation, but the "true culprit" is top management, says Herb Halbrecht of **Halbrecht Associates**, a Stamford, Connecticut, management consultant firm. Senior executives are reluctant to take risks or back projects that might not pay off for five to ten years, and despite the robots "depicted prominently" in U.S. manufacturers' annual reports, only about 10 percent of the companies have some genuine CIM capability, according to Halbrecht. One of the major problems is that automation experts in some companies report not to the VP for manufacturing but to the head of management information systems, who is traditionally concerned with finance and information rather than manufacturing but who nevertheless may resist surrendering responsibility for CIM. John Nostrand, also of Halbrecht Associates, finds some positive signs in the emergence of a "new generation of CIM experts" manufacturing systems engineers who have come up through the engineering or manufacturing departments or from process industries. Eventually, these experts will be coming from academic institutions with robotics programs, such as MIT, Worcester Polytech, RPI, Cal Tech, and Carnegie-Mellon. Demand for CIM executives will quadruple by 1990, Nostrand says. Meanwhile, Halbrecht warns, "Commitments [to CIM] have to be made now or manufacturing in this country may not survive 1990."

Companies are getting serious about factory automation, says the Cleveland-based executive research firm of **Christian & Timbers, Inc.**, citing a 34 percent increase over the past year in the demand for managers who establish and run automated manufacturing facilities. Most of the hiring is coming from corporations that are new to automation, and the top jobs are currently VPs of advanced manufacturing, VPs of engineering with automation experience, and directors of software development and of CIM.

A new report from the **Yankee Group** indicates that graphics on the shop floor could change the rules in manufacturing, putting factory line workers in control of the manufacturing process. Conveniently available graphics can bridge the "labor gap" between the highly trained technicians and engineers who design and support automated manufacturing

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systems and the unskilled operators who need to become more technically proficient in order to monitor and operate the systems. Shop floor graphics can be a support for line workers, rather than cause for their elimination, in that workers can get process and equipment information quickly and completely enough to make informed decisions on the appropriate actions to be taken. The Boston-based research firm's report describes factory shop floor graphics as being is in its infancy compared to its wider use in engineering and design, but the growth rate of shop floor installations will, in the next five years, overtake that of other applications.

Sales of machine vision products will grow at an average annual rate of 62 percent through 1990, with the automotive and electronics industries remaining the largest end users. The Machine Vision Delphi Study, conducted by the **University of Michigan** for the Automated Vision Association, represents the machine vision industry's first efforts to assess its own future. Among other predictions and conclusions: sales of machine vision products will reach $457 million in 1990, up from $58 million in 1985; vision systems sales will grow from $188 million in 1985 to $2 billion in 1990; in 1985, 49 percent of all shipments went to the automotive industry, but that number will decline to 31 percent in 1990 when 36 percent will go to the electronics industry and other industries step up their rate of use; gauging accounted for 27 percent of all vision products shipped in 1985, followed by inspection with 20 percent of the market; finally, over half the systems now in use are for dedicated, single process applications, and only a quarter of the installations are flexible, general purpose. The study described as the largest barrier to machine vision implementation a shortage of user expertise for developing applications.

A year-long study to help manufacturers predict and assess markets and uses for automated visual inspection systems is being proposed by **Battelle Memorial Institute** of Columbus, Ohio. The project will be supported on a multiclient basis by a number of interested companies, including both manufacturers and users of machine vision systems. The goals of the study, which will be carried out primarily at Battelle-Institut e.V. in Frankfurt, West Germany, are to describe and analyze currently available automated inspection methods and systems; provide an assessment of their efficiency, flexibility, and economy; identify potential uses; determine system adaptibility to other uses; and forecast major development trends.

CORPORATE NEWS

Parker Hannifin Corporation has announced a definitive merger agreement to acquire **Compumotor Corporation.** Compumotor stock will be converted into approximately

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600,000 Parker common shares. Certain Compumotor shareholders who hold in excess of 50 percent of the company's stock have signed separate agreements that give Parker the option to buy them out.

► **American Robot Corporation** has changed its name to **American Cimflex**, reflecting the company's transition from a manufacturer of robot systems to a broad-based manufacturer of software-intensive products and flexible systems for CIM. The firm consists of four primary business units: American Robot Division, Dynamac, American CIMSystems Division, and American Industrial Vision Corporation.

► John D. Horn, president of **Multivisions Corporation**, and Mathew Monforte, president of **Monforte Robotics, Inc.**, have jointly announced the acquisition by Multivisions of Monforte Robotics. Multivisions, an equipment leasing firm, plans to lease complete robotic systems. Monforte manufactures end-of-arm tooling. The parent company will provide some financial support and marketing. Monforte will join Multivisions' board of directors, and key directors of Multivisions will sit on Monforte's board.

► **Cincinnati Milacron** and **Hitachi America** have announced an agreement whereby Hitachi will supply Milacron with the T3-735, a five-axis robotic arm designed for arc welding and sealant applications, among other uses. The agreement is one of several outsourcing programs recently undertaken by Milacron. In November 1985 the company announced an accelerated restructuring of its machine tool and robot operations as a response to growing international competition.

► **Pattern Processing Technologies, Inc.** has established its Troy, Michigan facility as the firm's Automotive Systems Division. According to a company spokesman, the move will enable PPT to focus on the automotive industry's specific needs by supplying complete turnkey systems.

► **Cybotech Corp.** has received a $1.97 million order from Rocketdyne Division of **Rockwell International** for six robotic arc welding workcells. They will be used to TIG weld components for space shuttle main engines, and represent the first such workcells Rocketdyne will put into production as part of a NASA funded program to enhance manufacturing technology at the company's facility.

► **Seiko Instruments, USA** and **CR Technology** have embarked on a joint program to automate display and control panel test systems, using CR's System 240 machine vision-based tester and Seiko's D-TRAN robots. The initial results are a five-step operation: entering the system, intelligent LED displays are removed from their pallet by the robot and loaded into a fixture. The CR vision test system performs 2200 tests in less than 7 seconds, following each test with data reporting. The robot then unloads the fixture and palletizes the displays according to whether or not they passed the tests.

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ORGANIZATIONS

► **Jeffrey A. Burnstein** has been promoted to Director, Marketing and Public Relations at **Robotic Industries Association**, the 330 company-member robotics trade association. He has been with RIA since 1985 and was previously associated with SME and with a business promotional organization in Detroit.

► **Robert A. Day**, CMfgE, of Eastman Kodak, is the new president of **Robotics International of the Society of Manufacturing Engineers**. Day was a charter member of the Rochester Chapter of RI/SME and has held a number of positions within the parent organization.

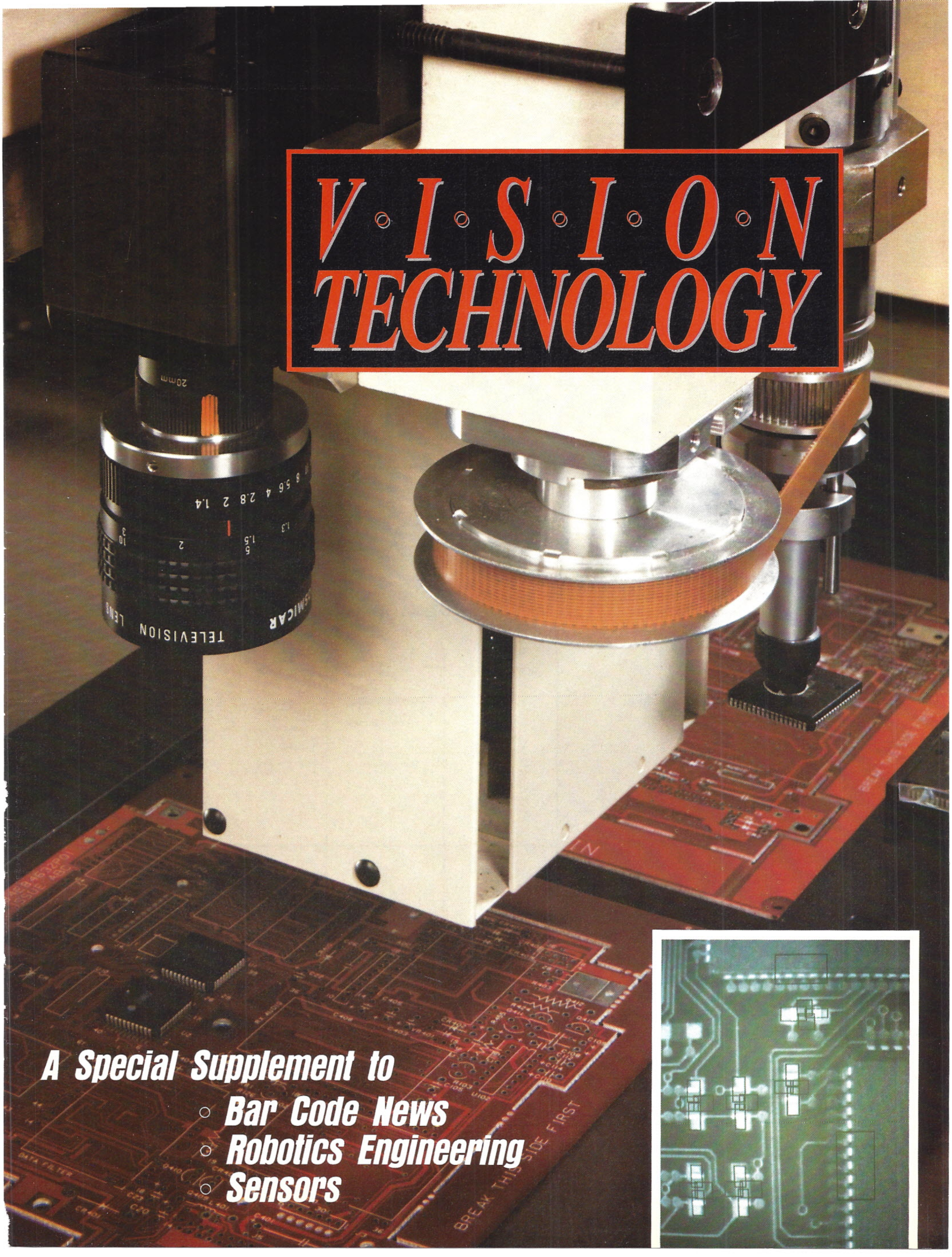
► **Computer Aided Manufacturing—International** has announced the release of its **Dimensional Measuring Interface Specification** for an automated communications link that provides a flow of inspection programming and measurement feedback between CAD systems and quality inspection devices and dimensional measuring equipment. The specification was developed by the CAM-I Quality Assurance Program as a result of a national survey and individual QAP sponsor requirements that indicated such an interface was the single greatest need of quality assurance within industry.

EDUCATION

Joseph F. Keithley, founder of Keithley Instruments, Inc., has personally funded a new **professorship in electrical engineering** at **MIT**. The chair will be known as the Joseph F. and Nancy P. Keithley Career Development Professorship in Electrical Engineering; Keithley's financial support will subsidize the chosen professor's salary and allow the recipient time for research work. MIT's **Dr. Martin F. Schlect**, assistant professor of EE, has been selected to receive the first Keithley professorship.

Ground has been broken for the **Advanced Robotics Research Institute—Fort Wayne**, a facility that will specialize in the applications of robotics, artificial intelligence, and related technologies. The institute will be staffed and operated by the engineering college of the **University of Texas at Arlington**. The $10M project is being jointly sponsored by **UTA**, the **Fort Worth Chamber of Commerce**, and Fort Worth developers **Newell & Newell**, who donated the 18-acre land site. A two-way TV system will be used to transmit classroom sessions between the institute and the UTA campus. Construction is expected to be completed by the end of this year.

V·I·S·I·O·N TECHNOLOGY



A Special Supplement to

- Bar Code News
- Robotics Engineering
- Sensors

The vision supplement cover photo, provided by Automatix Inc., depicts the Microsert SMD assembly system. Two cameras are used to direct component placement; one, mounted on the robot arm, registers board artwork and the second, mounted below the table, provides component lead inspection and registration. The Autovision controller matches component leads to board artwork.

The Fundamentals of Machine Vision Systems

Human vision is an enormously complex sensory capability that can be imitated, but not duplicated, by machine vision. Humans receive naturally diffracted light from a direct source, such as a flame; from refraction, such as the scattering of sunlight by moisture droplets in the atmosphere that produces a rainbow; and from reflection of light off an object. The brain interprets these signals, producing either a familiar or an unfamiliar "pattern," to be either recognized or studied and learned.

In a machine vision system, the camera(s) substitutes for the eyes and the computer(s) for the brain. Such a system can be used to interpret an image either to cause some immediate decision to be made during a production operation (e.g., move a part, reject a part, or avoid a collision) or to build a database about a series of workpieces so an analytical model can be developed to describe the expected characteristics of the objects. The system must therefore be able to verify object presence or absence, measure image features, and recognize objects.

Vision technology is new. Recent decreases in computer costs and increases in their capabilities have made them more feasible for use with vision systems. Further, a more sophisticated understanding of natural image processing has led to the development of corresponding algorithms that allow machine vision to more closely simulate that of humans. A third factor is hardware improvement. The development of solid-state cameras is essential to the generation of images.

The ultimate goal of an image recognition process is to reduce to a minimum the ambiguities, or the number of ways in which an image can be interpreted, using the least amount of information possible. At the lowest level, an object's location establishes its

TYPICAL MACHINE VISION PROCESS

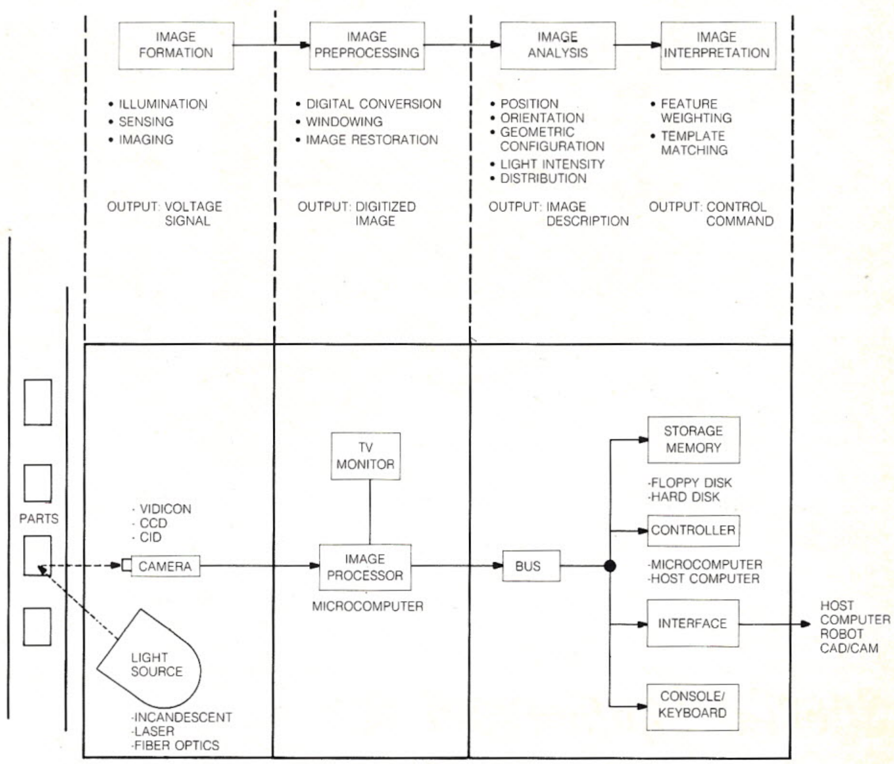


Figure 1. The machine vision process typically consists of image formation, image preprocessing, image analysis, and image interpretation.

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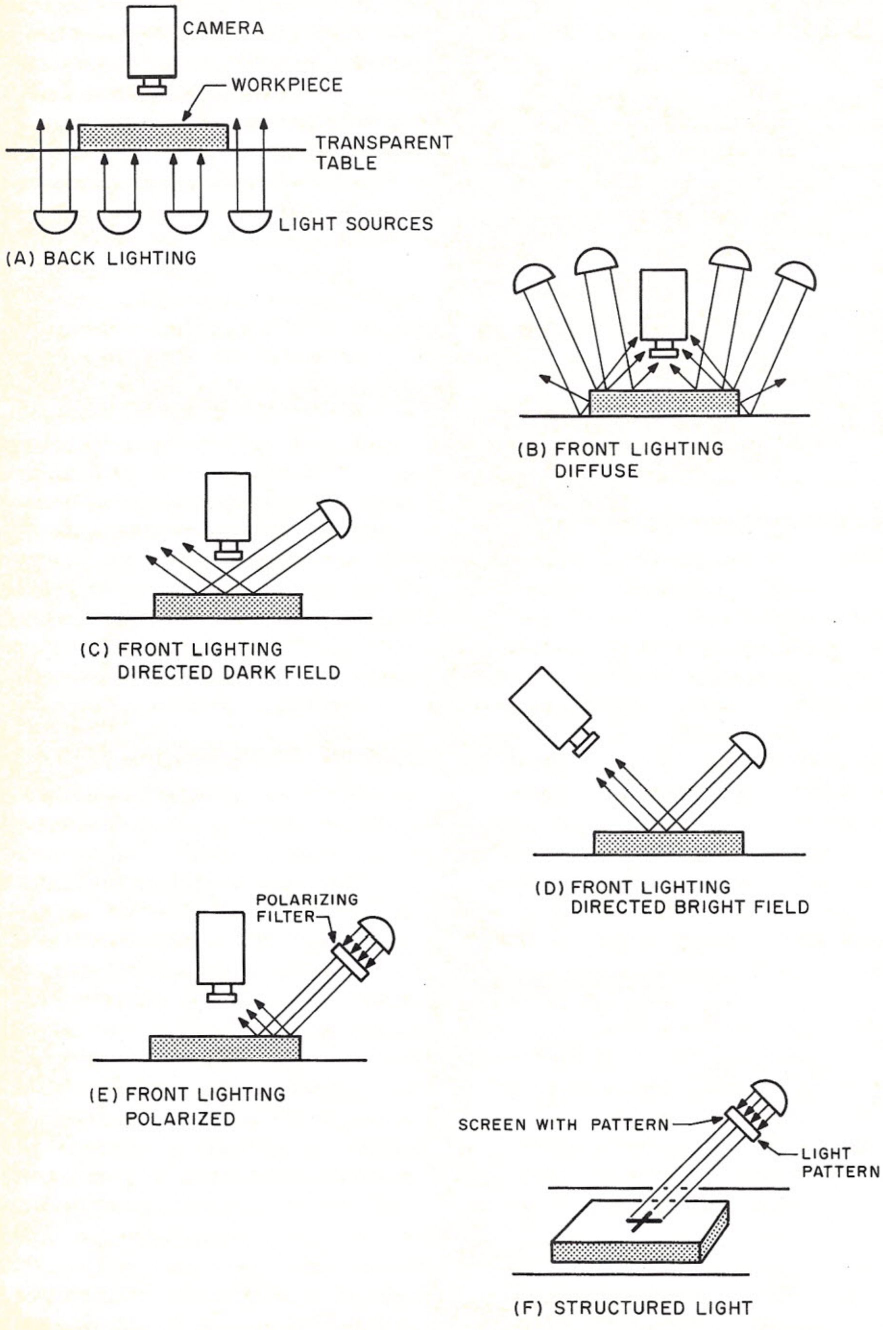

Figure 2. Placement of the light source depends on the workpiece features to be examined and the amount and nature of the information required about them.

identity. Higher up the ladder of difficulty is an indentification by its two-dimensional shape, requiring the analysis of subtle variations in light intensity on surface structure. Whatever the amount of detail required, the machine vision process consists of image formation, image preprocessing, image analysis, and image interpretation (Figure 1).

IMAGE FORMATION

The human eye forms an analog image of a perceived object, while a computer forms a digital image by means of discrete bits of data. The eye/brain system uses parallel processing to form an image, while machine vision forms the image sequentially, one bit at a time.

ILLUMINATION. Figure 2 illustrates six configurations of light source placement appropriate to typical applications of machine vision systems. Back lighting provides maximum contrast when only a simple silhouette is required; front lighting permits study of key surface features, such as a label; and side lighting is used to inspect for the presence of three-dimensional features. Light sources include incandescent bulbs, fluorescent tubes, fiber optics, arc lamps, and strobe lights. Lasers and polarized and UV light are used for special imaging applications.

SENSING. Once the scene has been properly arranged, the electronic imager acts as the system's sensing device. Its function is to supply the data that will be used for processing and interpretation. The imager is a sensor, collecting light from a scene (typically through a lens) and converting that light into electrical energy through the use of a

photosensitive target. Images are then generated as two-dimensional arrays, such as those formed by television cameras, or one-dimensional, linear arrays formed by scanning the scene one line at a time. Although a few machine vision systems use special purpose sensors for limited applications, such as lasers and ultrasonic sensors, most employ cameras.

IMAGING. The vidicon camera was popular in early vision systems. Able to provide a great deal of information about a scene and very quickly, it forms an image by focusing the incoming light through a series of lenses onto the photoconductive faceplate of the vidicon tube. An electron beam within the tube scans the photoconductive surface and produces an analog output voltage proportional to the variations in light intensity for each scan line of the observed scene. The total image is represented, as in commercial television, by 525 scan lines, interlaced into two fields of 262.5 lines, repeated 30 times per second. The limitations of vidicon cameras in industrial applications are that they tend to distort the image and are subject to image "burn-in" on the photoconductive surfaces. They are also susceptible to vibration and shock, and their useful lives are limited.

Solid-state cameras, employing charge-coupled device (CCD) or charge-injected device (CID) image sensors have become increasingly popular for machine vision systems. These sensors are fabricated on silicon chips, and contain matrix or linear arrays of small, accurately spaced photosensitive elements. When light passing through the lens strikes the array, each detector converts the portion of light falling upon it into an analog electrical signal. The image is thus broken into pixels, an array of individual picture elements. Solid-state cameras typically have a matrix array of 256 by 256 detector elements per array.

In order to generate a two-dimensional image, some sort of mechanical scanning device is required, such as rotating mirrors or movement of the workpiece, such as along a conveyor belt. The selection of the solid-state sensor type and its configuration for a particular application is influenced by a number of factors, including the resolution required, lenses employed, lighting, and cost.

Solid-state cameras offer several important advantages over vidicons: they are smaller and more rugged; their photosensitive surfaces do not wear out with use; and because of the accurate placement of their photodetectors, they exhibit less image distortion. Although they are at present more expensive than vidicons, solid-state camera prices are expected to decline in the future, leading to their widespread use in machine vision systems. Vidicon, CCD, and CID cameras are compared in Table 1.

Table 1
A Comparison of Typical Image Sensors

FEATURE	VIDICON	CCD	CID
Resolution	1	2	2
Sensitivity	1	2	3
Speed	3	2	1
Bloom	3	2	1
Size	2	1	1
Reliability	2	1	1
Current Cost	1	3	2
Future Cost	3	2	1

IMAGE PREPROCESSING

DIGITAL CONVERSION. The preliminary image produced by the camera must be processed so that it is presented to the microcomputer in a form suitable for analysis. A camera typically forms an image 30 to 60 times a second, and each image is captured or "frozen." Processing transforms the analog voltage values for the image into corresponding digital values via an A/D converter, producing an array of numbers that represents the light intensity distribution over the image area. The resultant digital pixel array is stored in memory until it is analyzed and interpreted.

Vision systems can be classified as:

• ***Binary.*** The voltage level for each pixel is assigned a digital value of 0 or 1, depending upon whether the signal's magnitude is less than or greater than some predetermined threshold. Each pixel is considered to be either white or black. This system is adequate for simple inspection tasks, in which a silhouette image can determine if a part is missing or broken.

• ***Gray scale.*** The fundamental process is the same as that of binary, but instead of two possible values for each pixel, gray scale permits up to 256 values. In addition to white and black, many shades of gray can be distinguished. This greater refinement allows objects to be compared on the basis of surface characteristics. Gray scale systems are also less sensitive to the placement of illumination than are binary systems.

The sophistication of gray scale imaging requires extremely powerful microprocessors. A 256 by 256 pixel array with up to 256 different values per pixel requires more than 65,000 8-bit storage locations; a data acquisition speed of 30 images per second produces so much information that the time required to process it can be significant. Yet, an ideal vision system would be capable of processing and interpreting all of this information in real time, especially when the system is used for on-line inspection or guidance and control of fast-moving equipment. A number of techniques have been devised and put into use to reduce the amount of data to be processed. Chief among them are windowing and image restoration.

WINDOWING. Windowing creates an electronic mask around a small area of an image to be studied, blocking out all pixels except those to be analyzed by the computer. This technique is useful for simple inspection applications in which presence is to be verified. A window can be virtually any size, from one pixel on up to a major portion of the image. Eliminating extraneous pixels reduces processing demands.

IMAGE RESTORATION. Image restoration is called for when an image suffers from various forms of degradation, such as blurring of lines or boundaries, poor constrast between regions, or the presence of background noise. Degradation can be caused by motion of the camera or the object during image formation, poor illumination or improper placement of illumination, variations in sensor response, and defects or poor contrast on the object's surface. Image restoration can be achieved by constant brightness addition, which adds a constant amount of brightness to each pixel, or contrast stretching, which increases the relative contrast between high- and low-intensity elements by making light pixels lighter and dark pixels darker.

Machine vision systems can perform other preprocessing operations such as edge detection and run length encoding. Edges are boundaries within an image

JML data recording lenses are high performance lenses ideally suited for facsimile use, CCD imaging, or any medium magnification range application.

The optics are extremely well corrected over large field angles, and the apertures are larger than previously available. In the past, no series of lenses had offered these desirable combinations.

JML offers two series — the 'A' Series and the 'B' Series. The 'A' Series of lenses are cost competitive and will resolve 200 dots per inch. Aberrations are minimized, and a full range of focal lengths is available.

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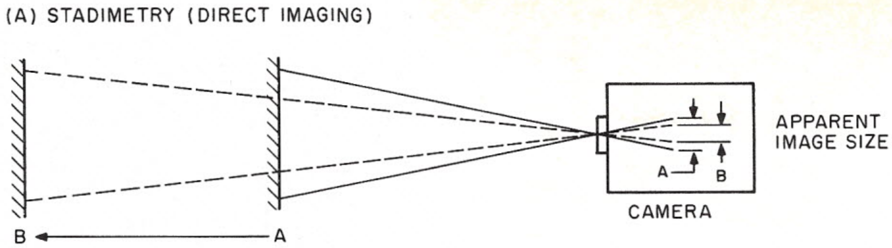

Figure 3a. Stadimetry is a technique for measuring distance based on the apparent size of an object in the camera's field of view. The farther away the object, the smaller its apparent image.

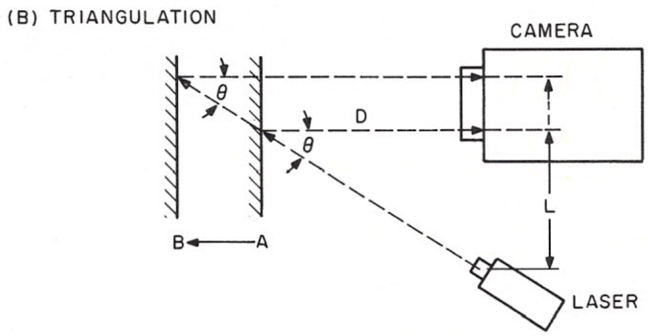

Figure 3b. Triangulation is based on the measurement of the base line of a right triangle formed by the light path to the object, the reflected light path to the camera, and a line from the camera to the light source.

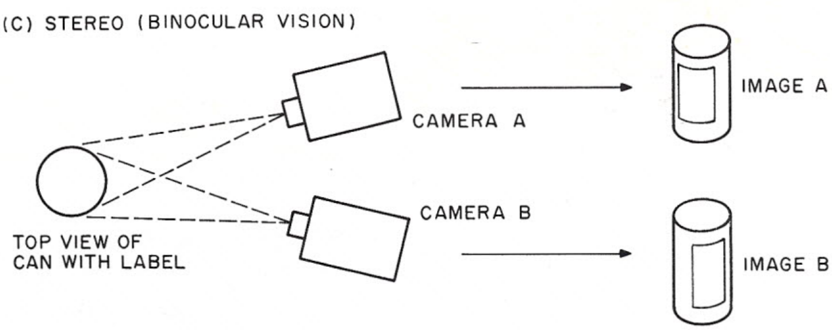

Figure 3c. Stereo vision uses the principle of parallax, or the change in the relative perspective of a scene as the observer (or camera) moves. The closer the object, the greater the parallax.

where there are dramatic changes in light intensity between adjacent pixels. Since these boundaries usually correspond to the physical edges of the workpiece being examined, they are very important for the inspection of part dimensions. Edges are usually determined by using one of a number of different gradient operators that mathematically calculate the presence of an edge point by weighting the intensity value of pixels surrounding the point. Thinning, gap filling, and curve smoothing ensure that the detected edges are only one pixel wide, continuous, and appropriately shaped. The vision system needs only to store the edges or some symbolic representation of them, thereby reducing the amount of required memory.

In run length encoding, each line of the image is scanned, and transition points from black to white or the reverse are noted, along with the number of pixels between transitions. This data is stored in memory and serves as the starting point for the image analysis phase.

IMAGE ANALYSIS

For conclusions to be drawn and decisions made, the digital image must be analyzed by describing and measuring the properties of several image features that might belong to the image as a whole or to regions of the image. This step is usually carried out by the system's central processing unit, and generally begins with an analysis of the simplest features and continues with the addition of complicated features until the image is clearly identified. The object's position and orientation, geometric configuration, and the distribution of light intensity over its visible surface are factors in this operation.

POSITION. When a workpiece must be positioned relative to a mating part, it might be necessary to monitor the location and orientation of that part in space. In a simplest-case scenario, a stationary camera can be used to obtain an image of a flat part on a conveyor belt. Its position can be determined by analyzing the pattern of pixels in the image. When, however, neither the distance between part and camera nor part orientation is known, other methods must be used to determine the distance (or range) of an object from the camera:

- ***Stadimetry***, or direct imaging, is a technique for measuring distance based on the apparent size of an object in the camera's field of view (Figure 3a). The farther away the object, the smaller its apparent image. Stadimetry requires an accurate focusing of the image, and an accurate determination of two known locations on the image surface. It minimizes errors caused by imprecise edge location.
- ***Triangulation*** is based on the measurement of the base line of a right triangle formed by the light path to the object, the reflected light path to the camera, and a line from the camera to the light source (Figure 3b). The angle between the two light paths is preset, and the distance L is measured, so that distance D is readily calculated. If the object moves from A to B, both D and L increase proportionally.

• *Stereo*, also known as binocular vision, uses the principle of parallax, the change in the relative perspective of a scene as the observer (or camera) moves (Figure 3c). The closer the objects, the greater the parallax, just as an object held close to the face will appear to move relative to some other object and to rotate slightly when observed first with one eye and then with the other.

ORIENTATION. Along with position, orientation of objects is important in operations where a robot needs to correctly position itself relative to a part in order to grasp and transfer it. This can be accomplished by:

• *Equivalent ellipse.* For the image of an object in two-dimensional space, an ellipse can be calculated that has the same area as that of the image. The major axis of the ellipse defines the object's orientation.

• *Connecting three points.* If the relative positions of three noncolinear points on a surface are known, the orientation of the surface in space can be determined by measuring the apparent relative position of the points in the image.

• *Light intensity distribution.* A surface will appear darker when at an angle other than normal to the light source.

• *Structured light.* The workpiece is illuminated by structured light, and the way the pattern is distorted by the part can be used to determine both the part's three-dimensional shape and its orientation.

Establishing both position and orientation of a part, especially one moving in three dimensions when six motion components must be defined (three rotational and three translational), presents particularly difficult problems, especially at high speeds and with a motion more complex than simpler linear displacement. Processing speed limitations for complex images can restrict the vision system's ability to track high-speed motions. One solution is a strobe that can be used to freeze images during motion; several hundred images per second can be captured by this method.

GEOMETRIC CONFIGURATION. In manufacturing operations, typical parts tend to have distinct shapes that can be recognized on the basis of very elementary features, and often identification is possible independent of part orientation. The first step of feature extraction, or determining these elementary image

properties, is to determine boundary locations and segment the image into distinct regions. Certain geometric properties of the regions are determined, and finally the regions are organized into a structure that describes their relationships:

• *Image segmentation.* This step, extremely demanding for a vision system, requires that the differences between the apparent and the real boundaries of an object be brought into agreement. What is observed and what is actually present must be the same.

• *Image shape.* The image outline or the shapes of certain segments may be enough to interpret an image. When an object can be differentiated from other objects solely on the basis of image size, features are measured through simple arithmetic calculations based on the number of pixels and their locations in the image.

• *Image organization.* The various image components, along with descriptions of corresponding features, can be structured by the vision system in a hierarchical fashion, in which the components are listed along with calculated values for each and the relationships among them. It is often possible to infer three-dimensional object structure in this way.

LIGHT INTENSITY DISTRIBUTION. One of the most sophisticated and potentially useful approaches to machine vision is the interpretation of an image based on the differences in light intensity in different regions. The problem with this method is that most machine vision techniques cannot deal with the complex patterns formed by varying conditions of illumination, surface texture and color, and surface orientation. One approach, currently in the experimental stages, assumes that the light intensity at a given point on the surface of an object can be precisely determined by an equation describing the nature and location of the light source, the orientation of the surface at the point, and the reflectivity of the surface.

Image Interpretation

The fourth capability required of a machine vision system is image interpretation, the conclusions formed by comparing analysis results with a prestored set of standard criteria. Machine vision deals in probabilities, and its goal is to achieve a probability of correct interpretation as close to 100 percent as possible. The two most common methods of interpreting images are:

• *Feature Weighting.* In cases where several image features must be measured in order to interpret an image, a simple factor weighting method can be used to consider the relative contribution of each feature to the analysis.

• *Template Matching.* An electronically generated mask is used as a template to which the system compares the pixels of a standard object with those of a test object.

Applications such as PCB inspection, weld seam tracking, robot guidance and control, and inspection of microelectronic devices and tooling have necessitated special purpose machine vision systems that incorporate unique image analysis and interpretation techniques. For example, some PCB inspection systems employ image analysis algorithms based on design rules rather than feature weighting or template matching. The inspection process would be based on known characteristics of a good product. The system would look for minimum conductor width and spacing between conductors and the presence of solder pads at the ends of the conductors.

Machine vision deals in probabilities, and its goal is to achieve a probability of correct interpretation as close to 100 percent as possible.

Factory Integration Of Vision Systems

Machine vision systems are nearly always used as part of a total factory environment. The data either becomes part of inventory control or it dictates appropriate actions to either a human operator or a robot. Vision systems can be evaluated according to certain established criteria. The importance of each depends upon the specific application:

• *Resolution.* This is the ability of a vision system to create a recognizable image from a particular feature of an object or scene. It is directly determined by the number of pixels in the image array and the image sensor's field of view. For a standard array of 256 by 256 pixels, the system can resolve portions of an object that just fit into the field of view down to a 1/256 of either the horizontal or the vertical dimension of that object. Resolution of a given array can be improved by using a camera lens with a higher magnification, but the field of view will then shrink.

• *Processsing Speed.* Image processing speed measures the number of bits that can be processed by the image processors. More important during on-line applications, however, is the speed at which individual items can be examined by the system. This is a difficult number to determine, since processing time is affected by many factors including image complexity, type of illumination, the accuracy required in interpreting an image, and whether or not windowing is employed. Typical vision systems can inspect and recognize simple parts at rates of 2 to 10 items per second; some can achieve speeds of 15 parts per second and higher.

• *Discrimination.* The ability of a vision system to discriminate variations in light intensity over an image is determined by the number of intensity thresholds present in the system. A gray scale system is able to preceive more subtle variations in intensity, but the tradeoff is that better discrimination means increased processing time, along with a greater computer memory capacity.

• *Accuracy.* A tradeoff can be made between processing speeds and the ability to correctly interpret images. A higher probability of correct interpretation can be achieved by processing more image features, which increases the processing time. Accuracy can be defined as the percentage of correct decisions made about a group of objects being examined. This number is a function of the variability of the objects, scene conditions such as illumination, the amount of teaching the system has received, the adequacy of the standard model used for teaching or programming, and other factors. An acceptable rate depends on the accuracy required by the application.

This material is adapted from Machine Vision Systems: A Summary and Forecast, Second Edition, *217 pp, Tech Tran Consultants, Inc., PO Box 206, Lake Geneva, WI 53147, telephone (414) 248-9510.*

Selected Glossary of Terms used in the Machine Vision Industry

Courtesy of **Ham Industries, Inc.**, 835 Highland Rd., Macedonia, OH 44056

A

Accuracy. The extent to which a machine vision system can correctly interpret an image, generally expressed as a percentage to reflect the likelihood of a correct interpretation.

Ambient light. Light that is present in the environment around a machine vision system and generated from outside sources. This light must be treated as background noise by the vision system.

Ambiguity. The characteristic of an image in which more than one interpretation of the object from which the image was formed can be made. There is no abiguity when only one interpretation is possible.

B

Binary image. A black and white image represented as zeros and ones, in which objects appear as silhouettes.

Binary system. A vision system that creates a digitized image of an object in which each pixel can have one of only two values, such as black/white or one/zero.

Boundary. The line formed by the joining of two image regions, each having a different light intensity.

C

CID, CCD, CPD. Charge Injection Device, Charge Coupled Device, and Charged Particle Device. Large scale integration, photo sensitive devices that are used as detectors in solid-state cameras.

Computer vision (machine vision). Perception by a computer, based on visual sensory input in which a symbolic description is developed of a scene depicted in an image. It is often a knowledge-based, expectation-guided process that uses models to interpret sensory data.

Controller. An information processing device that receives inputs from the vision system in the form of image interpretation data and then converts this data into command signals for robots or other equipment.

Correlation. A correspondence between attributes in an image and a reference image.

D

Detector. The light sensing portion of the electro-optical system. The detector translates gray level light patterns into equivalent analog or digital voltage signals.

Digital image. A representation of an image as an array of brightness values.

E

Edge. A change in pixel values (exceeding some threshold) between two regions of relatively uniform values. Edges correspond to changes in brightness, which can correspond to a discontinuity in surface orientation, surface reflectance, or illumination.

F

Features. Simple image data attributes such as pixel amplitudes, edge point locations and textural descriptors, or somewhat more elaborate image patterns such as boundaries and regions.

Frame. A single image at a specific point in time, sorted for processing and analysis by a computer.

Frame grabbing. Taking a scanned frame from a camera and putting it into memory for further analysis.

G

Gradient space. A coordinate system (p,q) in which p and q are the rates of change in depth (gray value) of the surface of an object in the scene along the x and y directions (the coordinates in the image plant). Thus p, q, 1 has the direction of the surface normal.

Gray level. A quantized measurement of image brightness, or other pixel property.

Gray scale image. An image consisting of an array of pixels that can have more than two values. Typically, up to 64 levels are possible for each pixel.

H

Higher level. The interpretive processing stages such as those involving object recognition and scene description, as opposed to the lower levels corresponding to the image and descriptive stages.

I

Illuminator. The use of a light source to generate a light intensity distribution based on the way in which light is reflected from an object's surface.

Image. A projection of a scene into a plane. Usually represented as an array of brightness values.

Image distortion. Relating to moving objects and the amount of distortion caused during a scan (1/60 second). Can also be caused by nonperfect optic within the camera lens device.

Image enhancement. The use of processing techniques to improve the nature of the information received from an image.

L

Linear array. A solid-state video detector consisting of a single row of light sensitive semiconductor devices. Used in linear array cameras.

M

Masking. The process of creating an outline around a standard image and then comparing this outline with test images to determine how closely they match.

Matrix array camera. A solid-state camera that forms an M×N array of pixels when generating an image.

O

Orientation. The angle formed by the major axis of an image relative to a reference axis. For an object, the direction of the major axis must be defined relative to a three-dimensional coordinate system.

P

Parallel processing. The processing of pixel data in such a way that a group of pixels is analyzed at one time rather than one pixel at a time.

Pattern recognition. The process of identifying an object based upon an analysis of several features of the object's image.

Pixel. A small element of a scene in which an average brightness value is determined and used to represent that portion of the scene. Pixels are arranged in a rectangular array to form a complete image of the scene.

R

Real-time processing. The ability of a vision system to interpret an image in a short enough time to keep pace with most manufacturing operations.

Region growing. Process or initially partitioning an image into elementary regions with a common property (such as gray level) and then successively merging adjacent regions having sufficiently small differences in the selected property, until only regions with large differences between them remain.

S

Solid-state camera. A camera that uses a solid-state integrated circuit to convert light into an electrical signal.

T

Template matching. Correlating an object template with an observed image field. Usually performed at their pixel level.

Thresholding. Separating regions of an image based on pixel values above or below a chosen (threshold) value or gray level.

Tracking. Processing sequences of images in real time to derive a description of the motion of one or more objects in a scene.

W

Windowing. A technique for reducing data processing requirements by electronically defining only a small portion of the image to be analyzed. All other parts of the image are ignored.

Machine Vision:

Coming of Age

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Machine vision is used to guide robot arms and automatic assemblers and to inspect parts, from automobile frames to the minute masks used to manufacture VLSI circuits. It is often used, as are robots, in environments that are too hazardous for workers, or to perform particularly tedious work. Machine vision is an essential element of automated manufacturing.

"Hard automation requires that you put everything in the same place at the same time, because it lacks the intelligence to look," says one Ford Motor Company senior engineer, Sonny B. Abbott. "Vision gives you the opportunity to take a picture of what you need to do. It gives the robot eyes and gets a little bit closer to humanizing the mechanical end of the business."

Abbott, whose group at Ford is responsible for examining cost justification for automated manufacturing equipment, explains the impact of machine vision systems on manufacturing.

"It takes what used to be done manually, from a hand/eye situation, with a person standing there, through a situation where we load a system and have someone watching the equipment run, to the point where we can turn the equipment loose and know the equipment is going to 'know' what it's doing. Vision systems give the manufacturer a way to handle complexities, turning hard automation into flexible manufacturing systems."

The Customer Profile

Machine vision has made its greatest impact on the automotive industry and in electronics assembly and inspection. In a recent *New York Times* article, General Motors was reported to be using more than 500 machine vision systems. However, they want 44,000 systems.

GM's William G. Neely, automation engineer at the Orion, Michigan plant, says, "The number doesn't seem that far out. We're not talking about a lot of sophisticated vision systems with 130 cameras (see sidebar "Two Giants with Vision"), but many very simple systems which are just checking for the presence or absence of parts on subassemblies coming off a line. They're relatively inexpensive systems."

While news that GM wants 44,000 vision systems is enough to warm the heart of any machine vision sales manager, in the recent past sales have not come that easily. Thomas F. Reynolds, director of Product Marketing at Automatix, Inc., in Billerica, Massachusetts says, "Customers don't fully understand what a vision system can do. Often they've been misled. Frequently, after a visit to our plant, a customer will have to go home to redefine what he wants a vision system to accomplish. We spend a lot of time in an explanation mode."

At Penn Video, a manufacturer of vision systems in Akron, Ohio, Gary Wagner, vice president for marketing, believes in a strong education effort. He says, "We believe in a long-term commitment. Our philosophy is that to sell a system today you must keep a

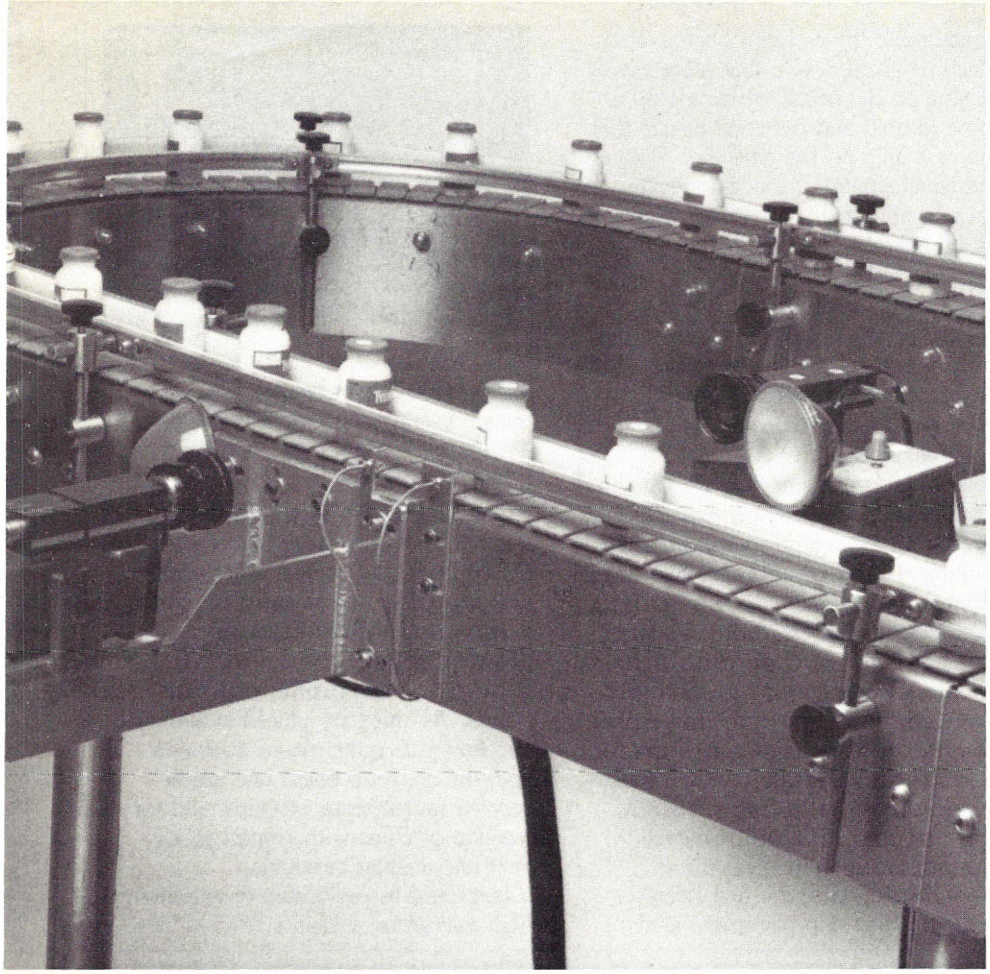


Photo 1. Cognex Corporation's package inspection systems can check label and cap positioning even when the bottles are randomly oriented.

satisfied customer." According to Wagner, half of Penn Video's yearly business is repeat business.

At Cognex Corporation, in Needham, Massachusetts, Judy Cobb, marketing communications manager, says of machine vision sales, "There's been a lot of evolution since we first started in 1981. Our customers then were only larger firms that didn't mind doing a lot of tinkering. They were interested in all the details of how a system worked. Now our customers are people who want a 'black box.' They want it to work, and don't care what's inside."

In Sunnyvale, California, at Adept Technology, Inc., a manufacturer of robots and machine vision systems, market development manager Elaine Wood says, "Over the last couple of years there has been an improvement in customers' understanding of what vision can do. There are more realistic expectations and the customer can see the benefits of a vision system." But, she adds, "Customers now also want their new vision system to be easy to install, to program, and maintain."

According to Wood, the main sources of buyer resistance come from two areas. They've heard that the systems work in the lab but not on the plant floor, and, there's the feeling that the same ends might be achieved with a simpler solution, e.g., an optical sensor, or some sort of actuator. "What we try to emphasize," says Wood, "is that rather than vision systems' being very high tech and complicated, by using vision the customer is actually simplifying things. There's less tooling and fewer interfacing problems."

The Future Of Vision

A number of vision companies are competing for the same limited amount of money. Depending upon whom you listen to, there may be as many as 200 companies selling systems or components.

In a positive assessment of the industry, Richard Schwartz, industry analyst with E.F. Hutton in New York, said in March, "Machine vision systems are going in and, in the last three or four months, they're beginning to work. There's no doubt that they're going to do the job. . .the worst is over."

While many vision systems marketing people agree with Schwartz, at least one corporate executive doesn't believe the worst is over.

Dr. Robert Shillman, president and CEO of Cognex Corporation, points out that ". . .because of all of those companies that were funded by venture capitalists, many of whom have been burned, there's not as much money available. Also, vision companies are still not yet profitable, although there are one or two companies showing marginal profitability.

"I'd say in five years the tough times will be over and the good times will be here," he continues. "Because there will be three to four well-established vision companies that are sharing the business, they will be able to raise their prices. Right now there are terrible pricing wars going on and many companies are delivering product and losing money on every sale."

"The good news is that it's a difficult business," Shillman comments. "It's not the kind of business the Japanese will come into because there's too much customization and market segmentation. Also, it would be folly for large corporations to come into the business. The ones that have been in the vision business have not done well."

Shillman echoes many others in the business when he says, "To be successful, a lot of experience is necessary. Of course, in the beginning people were inexperienced. You couldn't be experienced. . .Cognex went through all that. No one had the solution to any particular problem down pat. If they did, and tried to expand into a different industry, they found there were unique aspects of that industry that they had to learn. There has been a tremendous education in this business and the burden has been on the vision companies, to train not only their people, but the customer."

Two Giants With Vision

Machine vision has been embraced by the automotive and electronics industries as a key element of automated manufacturing. And, an increasing number of other industries are following in their footsteps as they find applications for the technology. If machine vision has not yet come of age, it is soon to do so.

The Ford Motor Company's Electrical and Electronics Division in Markum, Ontario, was confronted by a major engineering problem. Ten thousand high-density printed circuit boards for automobile radios are assembled each day, and because each board contains an average of 500 components, even a very small failure rate in component placement becomes magnified in terms of acceptable boards. For example, with only a 1 in 1000 error rate in placement, it means that every other board will fail.

Using the recently developed surface mount device (SMD) technology, Ford employs 30 TDK Avimount surface mount automated assembly machines to assemble these circuit boards. Each machine has a device that places spots of glue on the board where a chip is to be located and a second device that places a chip on the glue spot. Before the development of machine vision, each board was then visually inspected by an operator, and moved on to the wave soldering machine.

But human inspection of high-density circuit boards is not very successful, and repair of a defective board after it has been soldered is time consuming and costly. Nick Kakarelis, SMD Area Manager at Ford's Markum plant, notes, "Human inspection is about 80 percent effective on an average process, but when looking at chips on a board, it's around 50 percent.

To help Ford cope with the inspection problem, Automatix, Inc., of Billerica, Massachusetts, installed a machine vision system on each TDK assembly machine (Photo 2). Three identical boards are placed in a frame that is held by an x-y axis table. In step one, the first board is moved around until all glue spots are in place. In step two, the first board is shifted to the chip placement station,

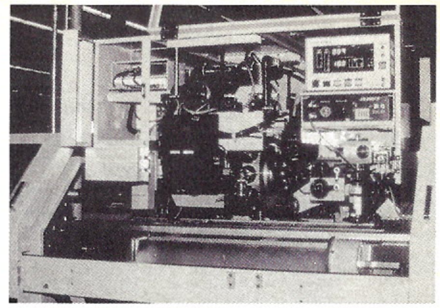


Photo 2. The cover of the Automatix TDK assembly robot slides away to reveal PCBs being populated with surface-mount components and afterward inspected by the same machine.

while the second board moves under the glue spot station. As chips are placed upon each of the first board's glue spots, the second board receives glue spots at the same relative positions.

The final station is the inspection station. As chips are placed at station two and glue spots placed at station one, the chips on board one are inspected for presence of chips, and for location of chips with respect to x,y, or θ, the angular orientation.

Inspection is performed to extremely high tolerances, within a field of view

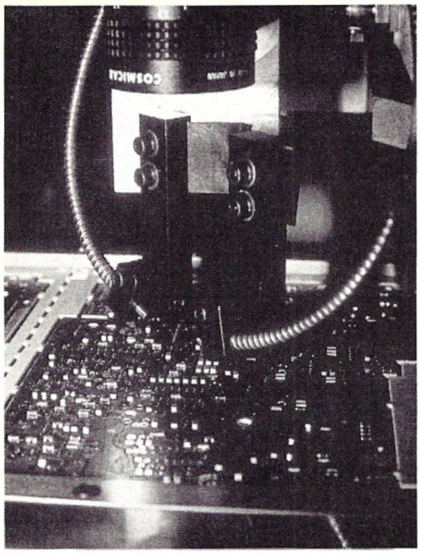


Photo 3. At the repair station, an operator places the frame on a table that automatically moves the boards to position beneath a microscope the location of a missing or defective component.

that is 0.4 in. square (Photo 3). No x-y deviation greater than 0.4 mm, a figure chosen to represent at least half the width of a component lead, is allowed. Skew can be no more than 7 degrees.

After the three boards have gone through all three steps, they are passed to a repair station. There, an operator places the frame on a table that also moves boards over an x-y axis, automatically positioning beneath a microscope the location of a defective or missing component. The operator then performs any repairs, after which the board is sent to the wave soldering machine.

The Automatix system has been in place for more than a year. According to Ford's Kakarelis, "Without the vision system we could not guarantee the quality. It would be very difficult, if not impossible, to operate without a vision system of some type."

General Motors Corporation has been a strong supporter of machine vision technology development, both in its funding of R&D efforts and in the use of machine vision systems on assembly lines. At the Buick, Oldsmobile, and Cadillac assembly plant in Orion, Michigan, GM has used a 130-camera, full-body checker to inspect for uniformity of build for more than a year and a half. The machine vision system, installed by Perceptron, Inc., of Farmington Hills, Michigan, examines door and body

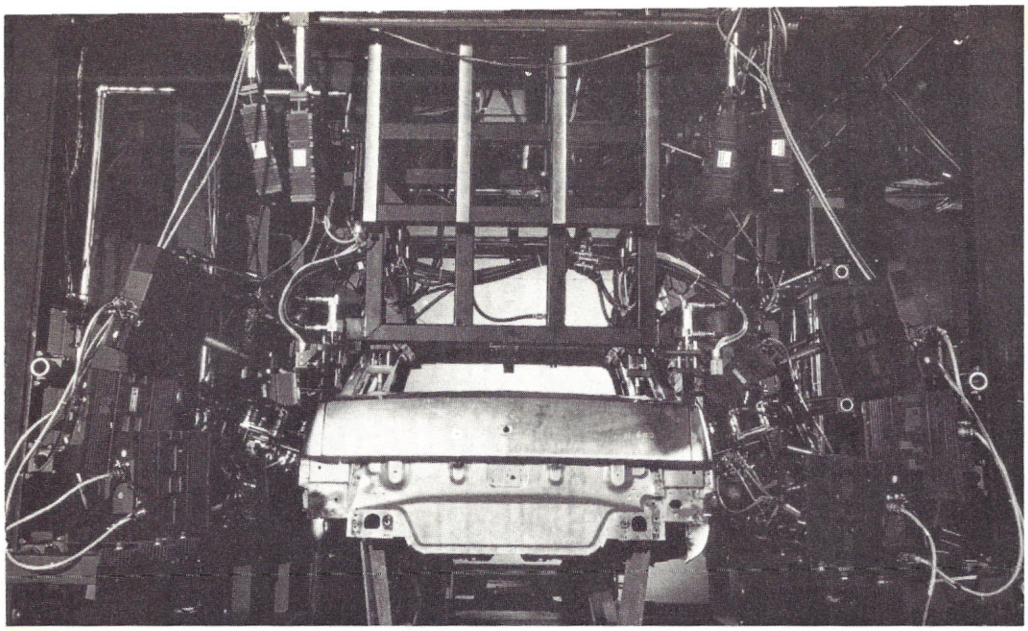


Photo 4. A Perceptron, Inc., 130-camera, full-body checker inspects for uniformity of build at GM's Orion, Michigan facility.

openings, and the overall dimensional integrity of five different styles of cars (Photo 4).

"The goal of the system," says William G. Neely, automation engineer at the Orion plant, "is to find any defects after the car has been framed and all major body parts have been assembled. . .One of its [the system's] greatest assets is getting the information quickly, so we can make intelligent decisions."

Formerly, using what Neely calls "hard gauges," they were unable to check more than one car a day of a particular style. If a defect was found, further gauging was necessary to determine whether it was a one-time defect or something occurring in several vehicles of that style. As a result, it took about a week to make an intelligent decision as to whether or not they should make a change. In the meantime, as many as 5000 cars had been produced.

In operation, the Perceptron system takes a complete look at each vehicle in less than 30 seconds. Car bodies in assembly are moved around on pallets to which they have been clamped. Because precise alignment of each body is required, each pallet has locating pins that fit into holes in the car frame (five different styles of cars move through the assembly line, but all are built on the same frame). Gauging is carried out in a three-way precision station, that holds the car body to within 0.005 in.

Once in the Perceptron station, data concerning the vehicle style is loaded into the computer and the system looks at whatever is necessary to gauge a particular opening. It may be a contour or a trim edge. It may inspect for one-, two-, or three-dimensional information, using various combinations of the 130 cameras, most of which use lasers (in the entire system, only about six cameras use fluorescent sources to obtain flat lighting).

"The result," says Neely, "is a better quality car. Everyone today is looking for uniformity of build, because it's the only way to get quality."

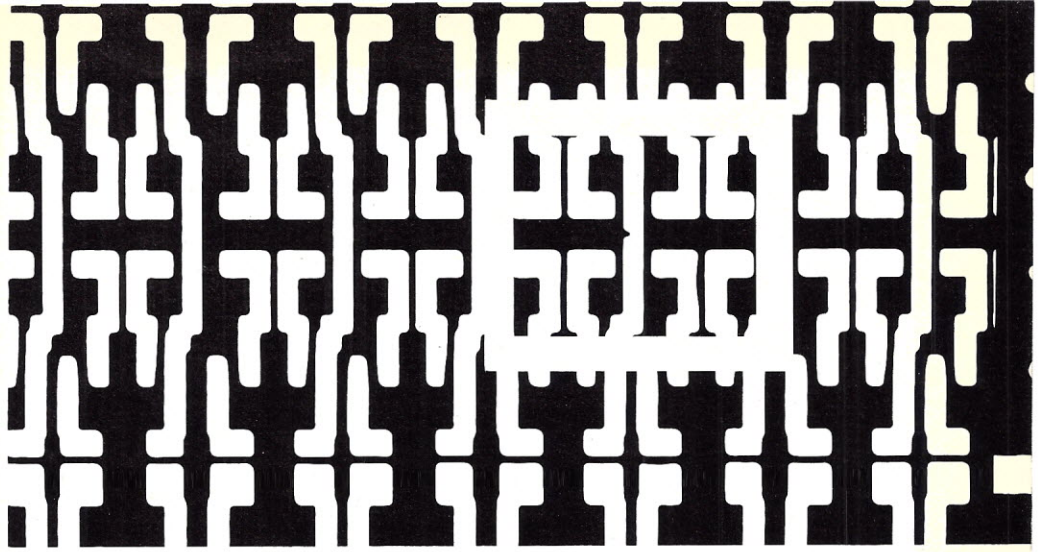


Photo 5. The KLA-228 Reticle Inspection System, designed to inspect masks used in sub-micron lithography, detected this 0.5 micron chrome extension situated in 1.0 micron linewidth geometry. To put these dimensions in perspective, consider that a human hair measures approximately 100 microns in diameter.

Spotlight On
Applications

KLA. Searching out flaws in the masks and reticles from which very large scale integrated (VLSI) circuits are made means making a trip into the sub-micron world. While a human hair measures about 100 microns in diameter, circuit line widths in VLSI circuits commonly measure about 0.75 microns. Mask inspection is critical, for if a defect is overlooked prior to circuit production, a manufacturer might produce thousands of components before the discovery is made.

KLA Instruments Corporation, of Santa Clara, California is one of only a handful of companies manufacturing equipment to inspect masks used in sub-micron lithography. Derek R. Granath, a KLA applications engineer, says his firm's equipment will define defects as small as 0.35 microns (Photo 5).

The KLA equipment is automated. The operator sets up an inspection area by defining several locations and the machine automatically scans by moving the mask on an x-y table. When it detects a defect, it stores the defect's location in memory. After the inspection, the operator goes back, reviews the defect locations, and classifies them according to type. The defect is then automatically positioned under a microscope, and the operator makes an identification.

To appreciate the complexity of the inspection task, imagine examining a 4 in. square photomask, on which there may be from 300 to 800 integrated circuits, and each contain thousands of devices, such as transistors, diodes, and resistors.

Penn Video. There are times when the objects one wants to see are hidden from view and another approach is required. The answer may be to

combine x-rays with machine vision image analysis. For example, a steel-encased automatic transmission clutch assembly may contain as many as 10 steel and fiber clutch plates. The sequence of these plates within the case is critical.

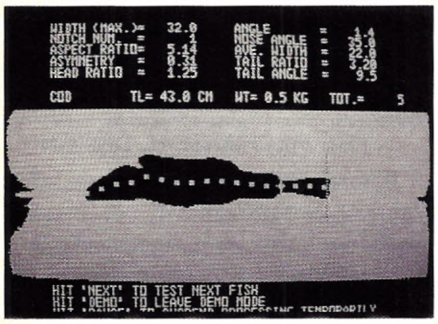
In the case of the Hydramatic Division of General Motors Corporation, Ypsilanti, Michigan, the task was to inspect fully assembled units to ensure the correct arrangement of clutch plates. Using two systems manufactured by Penn Video, of Akron, Ohio Hydramatic is now inspecting completed clutch assemblies at a rate of one every four seconds. According to Penn Video's Gary Wagner, vice president for marketing, the challenge in combining x-rays and machine vision lies in the processing. "Much of the x-rays are absorbed by metal, which means you get a pretty shabby image, so we use a high-speed processor that looks for the correct sequence of clutch plates."

But clutch assemblies are not the only application used for x-ray machine vision. Penn Video also has equipment looking for foreign objects in baby food jars and in canned soup. One baby food manufacturer has a tunnel built over the assembly line to serve as a shield to prevent escape of x-rays as baby food jars pass by at a rate of two to three per second. When foreign material is seen, the jar is rejected.

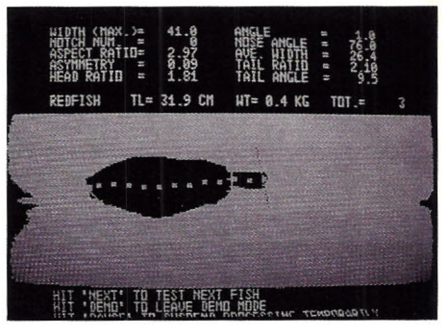
View Engineering. One out of ten aluminum cans is out of specification or otherwise does not meet standards, says Richard C. Ganz, director of sales for View Engineering, Inc., Simi Valley, California. His information comes from a study of aluminum can manufacturing processes conducted by his company's engineers. Ganz says that the new View 1115 machine is the first fully automatic, noncontact can body inspection system, and that it will examine both in-process and factory finished cans.

The device makes video measurements to an accuracy of ± 0.00025 in. of trim height, dome depth, flange width, plug diameter, and finished height. The device also performs air gauge measurements of can wall thickness to an accuracy of ± 0.000046 in. View Engineering is a subsidiary of Hughes Aircraft.

An Automated Fish Inspection System



Photos 1 and 2. The Fish Monitoring System analyzes and displays detailed information about a cod, left, and a redfish, right.



Octek has been developing machine vision systems for the food and pharmaceutical industries for eight years. The firm recently built a prototype vision system designed for the classification of fresh fish. The Fish Monitoring System (FMS) will eventually be an integral part of a shipboard data collection package that will inspect whole, fresh fish between the cleaning and the icing stations on fishing or research vessels. The FMS consists of a standard Octek computer and vision hardware, plus software tailored expressly for fish inspection. The prototype system is currently investigating the practicality of applying vision to the real-time automatic variety identification and weight calculation of fish as they move along a conveyor line.

Whole, gutted fish are processed as they are presented to the system at a line speed of up to 180 feet per minute. To ensure a constant flow rate and proper orientation/presentation, the fish are fixtured prior to inspection. The lighting source is placed underneath the fish so that they are back-lit, producing a consistent high-contrast image regardless of the shading or color of the fish. A binary image of each fish is stored, containing enough information to identify it by variety and to calculate its length. The length is defined as the distance between the tip of the nose and the tip of the tail (or the tip of the body, if the tail has been bobbed). If the fish is curved, the linear distance between its two ends will be less than its actual length and a more complicated algorithm is needed to calculate the length accurately.

The fish are automatically identified by the FMS as belonging to one of six types: Atlantic cod; pollock or haddock, Greenland or Atlantic halibut; yellowtail flounder, witch flounder, winter flounder, or American plaice; redfish; and catfish. Fish of other types are simply called "other." Once a fish has been identified, its weight can be estimated from its length. This correlation between length and weight is good but not perfect; wide differences between calculated and actual weights may occur for individual fish but they are expected to average out with large samples of fish of a given group.

Although the Fish Monitoring System is as yet in prototype form, one can conceive of a "factory of the future ship" hauling in the catch. Fish to be processed as fillets or frozen blocks could be diverted in one direction, while those destined for animal feeds and fertilizer could go in the other. Length and width information could translate into up-to-the-minute dollar value beamed via telecommunications satellite to the fishing company's marketing office on shore. A company armed with such current data would be able to maximize profits at the daily fish auctions while at the same time operating its fleet more efficiently and with smaller crews.

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Rapid Robotics Development With Real-Time Software

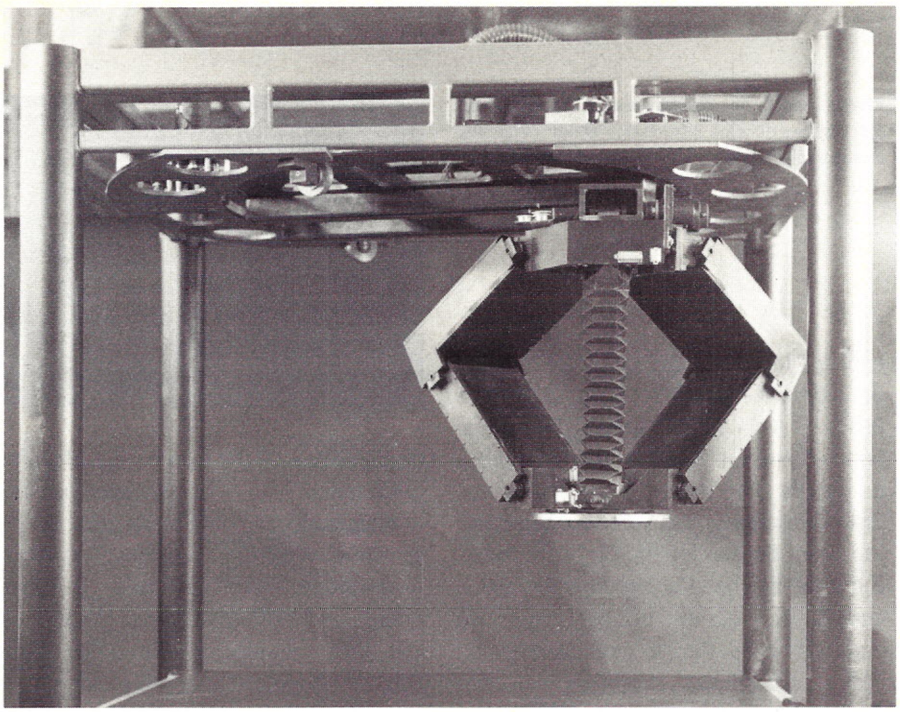

Photo 1. The arm is suspended from two overhead radial axes that rotate independently to produce true X-Y positioning.

When Elicon decided to branch out from robot camera control systems for the entertainment industry to the industrial robotics field, it set its engineers to the task of designing a flexible robotic system capable of performing a variety of jobs with ease of changeover being a primary consideration. As is frequently the case with such projects, the selection of software was a critical element in its success.

Elicon wanted this system to be fast, repeatable, and accurate. The company also wanted it to provide a safe work environment. The goal was to create a work area that would make use of the maximum available ceiling height. Since the system had a gantry design, maximum use of the table-top work surface (which can be up to 20 ft by 20 ft, with a vertical manipulator arm up to 8 ft long) had to be accomplished without arms hitting the gantry support pillars. The mechanical design also had to be flexible enough to incorporate a variety of optional inspection and assembly devices ranging from optical measurement systems to manipulators.

To get the product to market quickly, the software had to be able to control the complex geometry of the gantry without excessive development time. It also had to allow the operator to make on-site modifications quickly in a real-time environment and had to have multitasking features.

THE MECHANICAL DESIGN

Several years of R&D produced an unusual configuration of two overhead radial axes that rotate independently to generate true X-Y positioning. The gantry uses a proprietary friction-drive technology to produce five axes of motion, each capable of smooth, positive movement. Accuracy is controlled by direct encoding of the load-bearing members of the system.

The two overhead radial movements are a revolving disk and a rotating arm located on an eccentric point on the disk. The arm is allowed to rotate ± 720 degrees and is designed to clear all vertical supports. The support disk is allowed to revolve a full ± 720 degrees. The disk is supported by three angular capstans. Using a friction drive and a unique friction-drive encoding system, the rotating disk axis is capable of extremely fast accelerations while retaining positional repeatability of 8 sec. Because the disk is kinematically supported at its edges, flatness is ensured even during rapid accelerations. Since the arm is located at the perimeter of the disk, it is possible for both members to add their velocities to generate even greater speed of movement in the workplace, without sacrificing accuracy or repeatability.

The remaining three axes (yaw, pitch, and elevation) are also friction-driven with

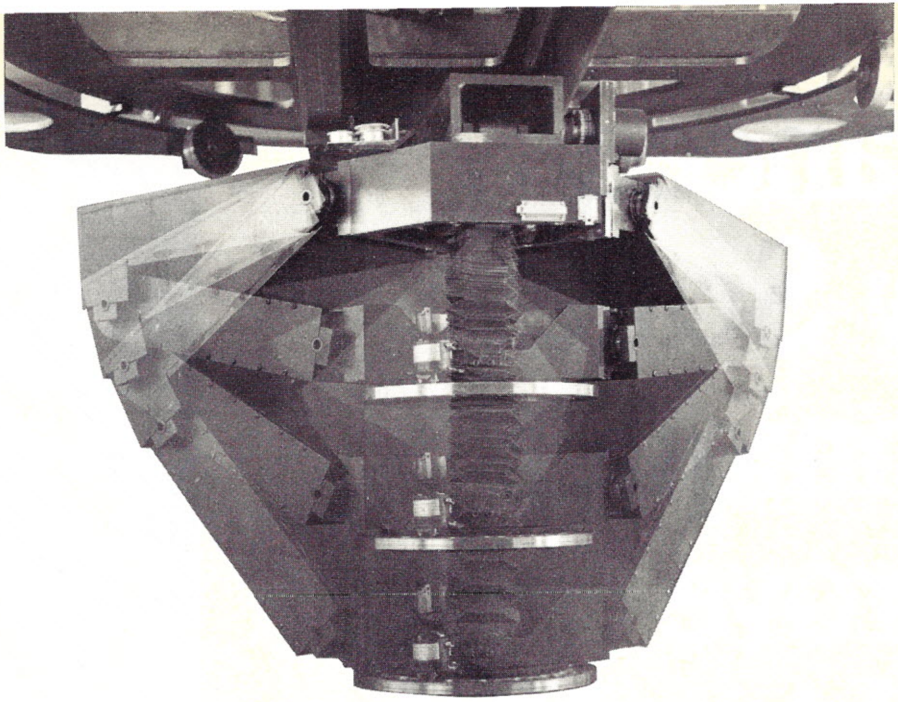

Photo 2. Friction-drive technology ensures smooth, positive movement through five degrees of freedom.

load sensing encoding for added repeatability. The friction-driven gimbal used on the pitch and yaw axes provides extremely smooth movement and can position a 150-pound end effector with a repeatability of ±0.001 in., assuming constant temperature and humidity.

The friction drive provides a unique programming function, allowing the operator to move the apparatus manually and repeat the movement later, using the control system. The drive also provides a unique safety feature: the breakaway design allows users simply to push the system out of the way with very little effort. The robot can then return to its original position and resume its path of motion. This feature minimizes the need for elaborate safety measures, such as shutdown nets or ultrasonic fields to protect operators working near the robot.

THE SOFTWARE

The operating system chosen for the robot was polyFORTH® (FORTH, Inc., Manhattan Beach, CA). Characteristics leading to this selection were:

- speed, flexibility, and efficient, compact code
- a dictionary-oriented structure that permits easy modification by even the nonprogrammer
- a real-time multitasking capability that can easily handle the many complex and disparate functions requiring concurrent execution in robot-related applications
- an interactiveness that provides the necessary tools to write software rapidly, thus keeping costs down while permitting alternative routes to be programmed and explored to create the best software model

The integrated structure of polyFORTH is the primary factor contributing to rapid interactive development. The integration into one programming environment of a high-level language and real-time operating system, plus resident compiler, assembler, editor, and programming utilities eliminates delays caused by the separate steps of editing, compiling, link-editing, loading, and, finally, testing.

Elicon has used polyFORTH running on Digital Equipment Corporation's LSI-11 computers for robots and servocontrol systems since 1979. Its real-time performance has allowed us to develop products using much less expensive hardware than required by comparable systems, and with better overall response times as well as support for a convenient user interface and advanced features. The feature that has proven most valuable to us has been the ease with which we have been able to modify our application programs to handle new designs. The new geometry of the gantry was incorporated into previously existing operational application software. The transformations required real-time conversion of Cartesian coordinates to the system's quasi-spherical geometry.

The software allowed the entire geometry of the system to be integrated with the existing control software to form an operational system less than 48 hours after a statement of system requirements was completed. The entire system for the gantry was, in fact, completely developed in one week. This extremely short cycle was made possible by the ease with which previous programs could be modified to support the new geometry and different application focus. As a result, the software was fully operational well in advance of the mechanical system; using the completed software, mechanical subassemblies were tested so that any mechanical defects could be diagnosed and rectified before final assembly.

Our programmers found polyFORTH so easy to use that they could easily write a small program to test one particular aspect of the system within minutes of being requested to allowing our mechanical designers to test concepts quickly without risk of a heavy software overhead. We believe this one factor alone substantially reduced our overall development time on the project.

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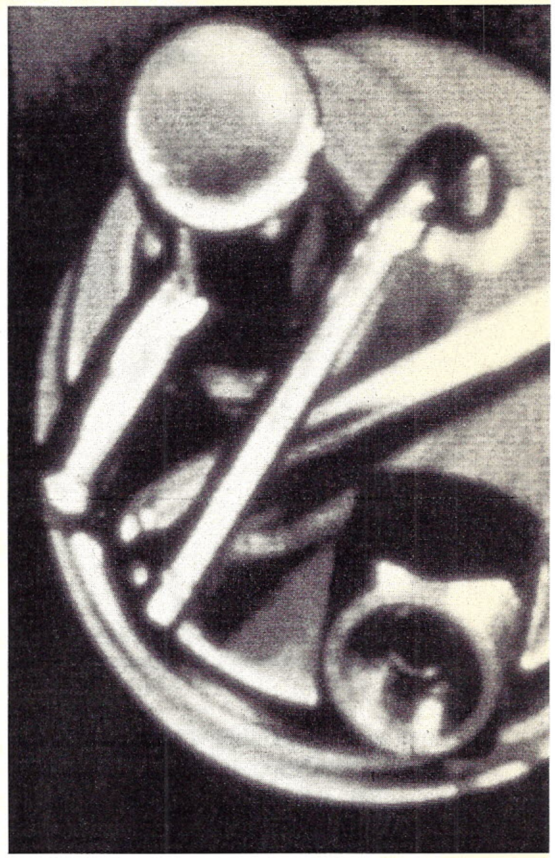
Advanced Gray Scale Techniques Improve Machine Vision Inspection



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Machine vision is a technology that employs computers and video cameras to analyze and interpret images in a manner resembling human vision. These systems provide visual feedback to manufacturing equipment such as robots, motors, conveyors, actuators, and alarms through an I/O module (Figure 1). The prominent application for machine vision is the inspection of discrete parts during manufacturing and assembly.

The largest users of machine vision thus far have been in the automotive industry, where inspection systems are improving quality and productivity and lowering manufacturing costs for General Motors, Ford, and Chrysler. However, many other industries such as electronics, health care, food and beverage, glass and clay products, packaged chemicals, and paper products are now beginning to install machine vision systems and to realize the same benefits.

Because many of the earlier generation machine vision systems require expertise in fields not usually available to the manufacturing engineer, some potential applications went unaddressed and other attempts to use the technology were outright failures. These systems demand knowledge of lighting, computer languages like FORTH or Pascal, image algorithms, TV cameras, and expertise in adapting general-purpose computers to factory floor requirements—a diverse and formidable combination of skills. Most vision applications development, therefore, has been carried out by vision systems suppliers or by outside consultants.

Machine vision should be as easy to use as programmable controllers, or perhaps even easier; they should be controllable by the people who use them every day, and not require outside experts. The following are important attributes to keep in mind when evaluating machine vision systems.

- Installation should be quick and easy.
- The lighting should not have to be uniform, and the parts should not require any special background, like a

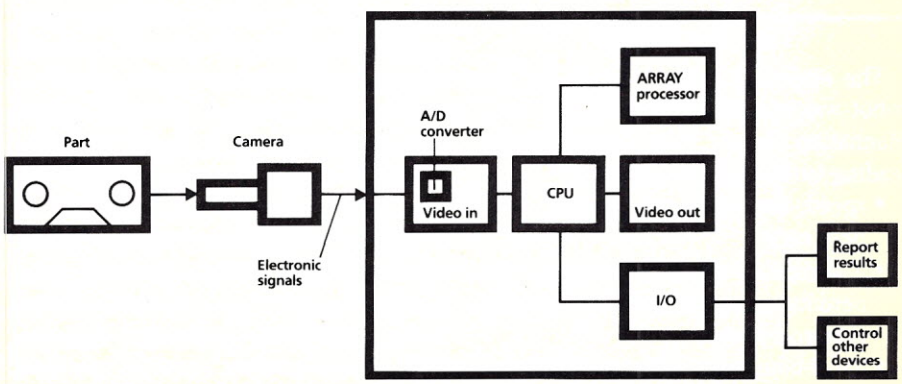

Figure 1. The steps by which images received by a machine vision system camera are analyzed and interpreted are shown in this simplified diagram.

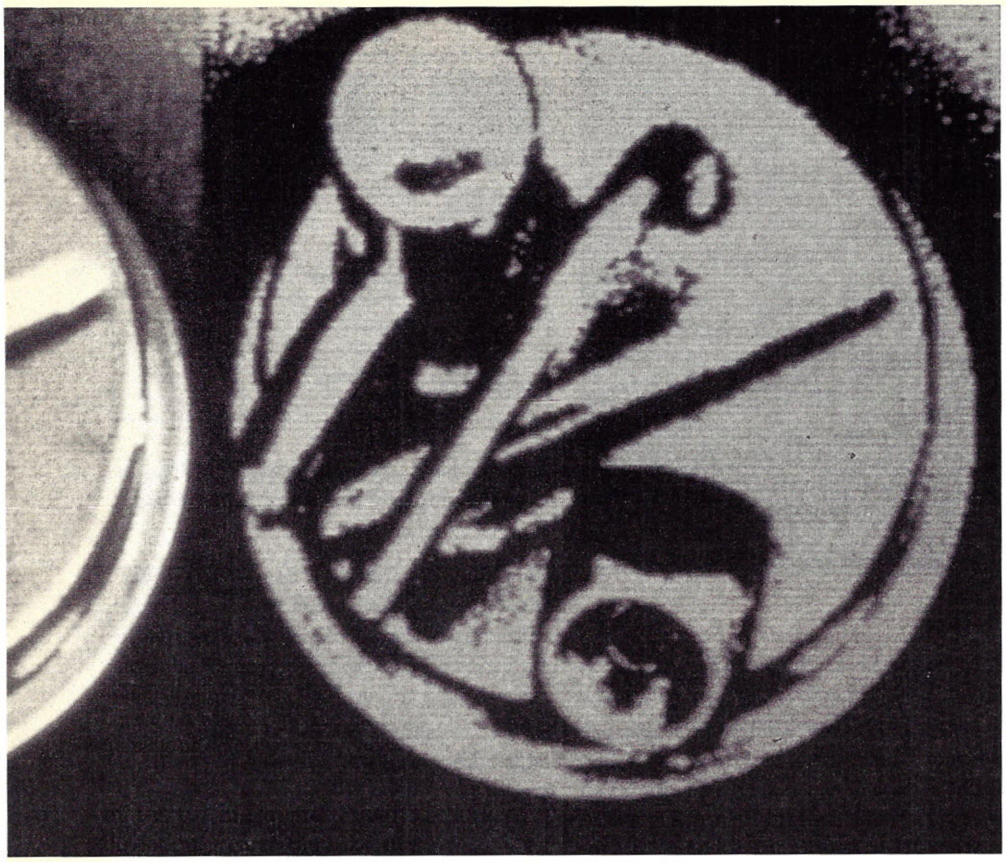

Photo 1. Gray scale imaging (left) provides more image details than a binary system (right).

white conveyor belt when imaging dark parts.

- Programming should not require any special expertise in computer science or image processing technology.
- Any modification of the inspection process should be a simple operation. The system should allow easy fine tuning on the factory floor by the end user.
- The system must exhibit the highest degree of reliability; if something does go wrong, fast repair is of paramount importance.

GRAY SCALE IMAGING

The most common technique for machine vision inspection in the past involved converting the continuous tone (or gray scale) image seen by a black and white TV camera into a binary image consisting of points that are either all black or all white. Accordingly, these systems are referred to as binary imaging systems.

A binary system requires considerable skill in optics and lighting so the "thresholded" image is a reasonable facsimile of the part. In many cases, this is extremely difficult to accomplish; it is sometimes impossible. Once an image is converted to binary, a great deal of information can be lost, even with good lighting and optics, during the conversion process. If the lighting varies even a small amount, for example, the complete image can come out all black or all white.

A gray scale machine vision system divides the amount of reflected light into a number of discrete gray values. True gray scale, as offered by Itran Corporation, divides light into 64 shades of gray—more than the human eye can see but visible to the camera. Photo 1 shows a comparison of a gray scale image (left) and a binary image (right). The images are stored in memory in an x,y arrangement. Gray scale imaging can handle the four major challenges of machine vision: position variation, varying lighting, varying surface finish, and low-contrast parts. The four major steps of the inspection process are:

1. **Find the part.** Where is the part in the field of view? How is the part oriented?
2. **Recognize the part.** Is this the part we are looking for? This is especially important if the vision system is sorting parts.
3. **Inspect the part.** Look for the presence of all features. Are key dimensions within spec? Have all assembly or fabrication operations been completed? Are all the parts present? Are there any blemishes or flaws?
4. **Report the results.** The last step in the vision process is typically to control some piece of machinery via an I/O device to deflect bad parts, sort different kinds of good parts, or position a robot.

FINDING AND RECOGNIZING PARTS

Gray scale processing requires two basic algorithms: edge detection and correlation. The Sobel algorithm is the most commonly used algorithm for edge detection. Every pixel is subjected to the following operations:

a	b	c
d	e	f
g	h	i

grad x $(a \times 2d \times g) - (c \times 2f \times i)$
grad y $(a \times 2b \times c) - (g \times 2h \times i)$
Sobel $\sqrt{\text{grad } x^2 + \text{grad } y^2}$

Gradient x represents the vertical edges and gradient y the horizontal edges (Photo 2). Since this procedure is repeated for every pixel, most gray scale systems use array processors to handle the math. Array processors, with parallel computing elements and high-speed circuits, tend to run 10 to 100 times faster than microprocessors during image processing.

Correlation is basically a process of matching two patterns, the pictorial image and a template. This operation produces a nonpictorial correlation image whose brightness indicates how well the template matches each local neighborhood in the original image. Intense dots indicate areas of high match (Figure 2). The complex math used in correlation also requires the use of high-speed array processors.

In Itran's implementation, gray scale im-

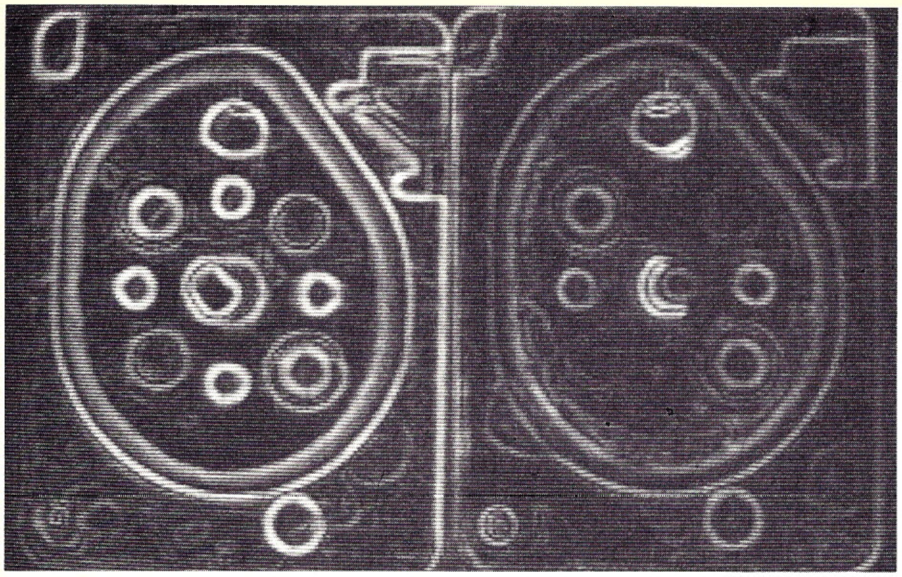

Photo 2. Edge detection enhances the features of both parts.

age processing techniques can be inbedded in a "toolbox" the consists of graphic jigs and gauges displayed on the programmer's screen. The tools are easily manipulated by the operator's light pen and placed over jig points and features to be inspected on images of parts. Gauges and jigs have mechanical counterparts that simplify the understanding of how they work.

Positioning Pins. Part positions vary during inspection, rarely coming down the line in precisely the same orientation. Parts can be jigged electronically, however, using Itran's positioning pins that operate like the positioning pins a toolmaker uses in designing hard mechanical jigging. To train a system to find and recognize a part, the operator positions three pins over the

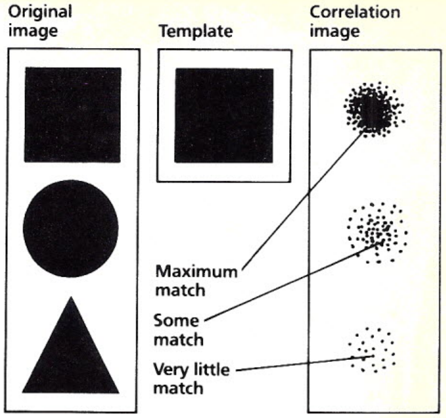

Figure 2. Intense dots indicate areas of high match between the template and the correlation image.

gray scale image on the programmer screen by means of a light pen. These positioning pins serve to locate the part. If the part moves because of translation or rotation during the inspection process, the part's coordinate system is translated or rotated according to location of positioning pins.

Operation of the positioning pins relies on feature extraction techniques. Each pin has an associated search area (how much the pin, and therefore the part, is expected to move). A nominal size for the search area is 32 by 24 pixels, or 10 percent of each axis of a 320 by 240 field of view. Since the search area size depends on how much the part position can vary, the user can increase or reduce it—the larger the search area, the longer it takes to find the part.

The "patch" of the picture inside each of the three search areas is edge-detected using the Sobel edge detector. The central 7 by 7 portion of the Sobel pattern is stored as a template for each positioning pin while the object is being taught to the system. The distance between the centers of the positioning pins and the angles between them is also stored. These distances and angles can be thought of as describing a triangle whose apexes are the centers of the positioning pins.

When inspecting parts, the edge template is correlated, or matched, over the Sobel edge-detected search area for each pin. When correlation is complete, the peaks determine the location of the best match between the template and the patch. A correlation operation is next carried out to best fit the triangle to the peaks in the three patches. The result is the x,y and angular offset corresponding to the

shift of the part. Once the offsets are known, all subsequent measurements can be done in a rotated and translated coordinate system.

Positioning pins can also be used to sort parts. Three features, appearing in one object and not in another, permit reliable sorting. Positioning pins can be used to help robots find the precise location of parts to be picked up or manipulated.

INSPECTING AND MEASURING PARTS

Once the part has been located and identified using the positioning pins, inspection and measurement take place. In Itran products, inspection is carried out using graphic gauges that work over a broad range of part motion. Calipers are used to make measurements and to report whether a measurement is, or is not, within tolerance. During the teaching mode, the caliper is positioned over the features to be measured and the blades are automatically "snapped" onto the appropriate edges. The caliper memorizes the edge pattern in the neighborhood of the blades and stores this pattern. During inspection, the templates corresponding to each of the blades are correlated with the edges of the images along the length of the caliper and the distance between the correlation peaks is measured.

The inspection task often consists of detecting the presence or absence of a certain feature. One reliable way to look for defects is to determine how consistent the amount of "edginess" is in a given area. Edginess is the total number of edge pixels in the area; an edge pixel is one whose Sobel value is greater than 16. The operator training the system positions a box around the area of interest and the system reads back the number of edge pixels in the box. The operator then establishes tolerance limits, the amount by which this number may vary and the part still be considered good. The defect finder position is coupled to the coordinate system as determined by the positioning pins, so part motion does not invalidate the measurements. The test results of machine vision inspection are either reported to a host computer, or, more often, used to control the machinery that sorts parts or deflects bad parts. Relay ladder logic, developed for machine control, is an appropriate and widely understood representation of the control process and a flexible alternative to computer languages.

CONCLUSION

The use of jigs and gauges, combined with relay ladder logic, gears machine vision toward mechanical and control engineers. Sophisticated gray scale image processing that combines edge detection and correlation provides a reliable means of dealing with varying parts position and lighting conditions. The result is a machine vision system that is robust and easy to use.

Stanley N. Lapidus is President of Itran Corporation.

Reader Feedback

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6	16	26
Excellent	Good	Fair

Machine Vision for Industrial Inspection and Gauging

Mary E. Doyle
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72 River Park Street
Needham, MA 02194

With the growth of industrial automation, it has become increasingly important to inspect the quality of manufactured parts during production. Until now, human visual inspection has been the primary means to this end, but the speed of today's production lines, the complexity of production equipment, and the fine tolerances to which parts must adhere frequently make human visual inspection impractical, if not impossible. New solutions developed for industrial inspection and gauging include LED-based or structured light systems, laser systems, and machine vision systems.

While structured light and laser systems can be effective for making a single measurement and associated accept/reject decision per part inspected, these systems often fail or become prohibitively expensive when an application requires multiple inspections and measurements or complex decisions for each part. Machine vision systems, on the other hand, can make multiple measurements for each part and can produce the types of reports required for effective production control.

A typical machine vision system consists of a camera to capture images of the parts to be inspected, a processor to analyze and interpret the captured image for relevant information, and a monitor and keyboard for use in system setup and result reporting. This type of system examines a part, evaluates its acceptability according to defined quality standards, and issues a decision about it to production control equipment. Part evaluation typically is based on a comparison between the captured image and a **standard** or **golden sample** of the part stored in the system's memory. This model of the part is usually derived either mathematically or, more frequently, by using the system camera to capture an image of an ideal part.

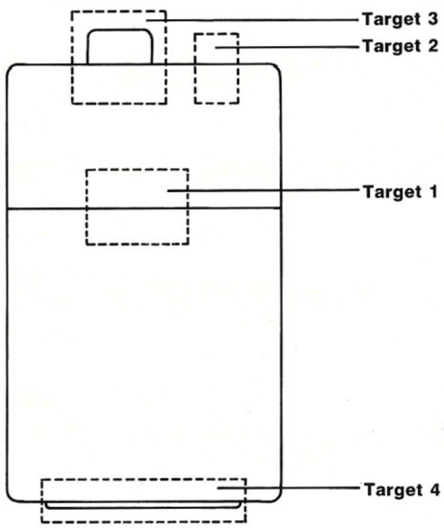

Figure 1. The system inspects four targets on each battery: the registration line where the shrink-wrap's two colors meet (1), the shoulder of the battery at the positive end (2), the positive tip (3), and the negative tip (4).

Systems can increase both their precision and their speed by concentrating only on these elements of a part where defects are likely to occur and by ignoring irrelevant areas of the captured image. By concentrating on specific features or **targets** on each part, a system can analyze the image at a higher resolution (thereby detecting smaller defects) while still maintaining the throughput required for production.

A VARIETY OF APPLICATIONS

Vision systems have proven effective in a variety of industrial inspection and gauging applications.

Batteries. In one application, a system inspects batteries at a rate of 450/min. for correct registration of colors on the shrink-wrap cover of the battery can, correct

length and width, and correct formation of positive and negative tips. The measurements made by the system are accurate to within 0.015 in. The batteries are on a conveyor and the inspection system is triggered by the conveyor's shaft encoder. A single camera looks at each battery, which is illuminated by two strobes with fiber-optic light delivery. The system inspects four targets on each battery: the registration line where the shrink-wrap's two colors meet, the shoulder of the battery at the positive end, the positive tip, and the negative tip (Figure 1).

Battery inspection proceeds as follows:

1. Inspect the registration line where the shrink-wrap's two colors meet (Target 1). If the target passes inspection, the registration of the two colors is within general tolerance; continue inspection. If the target does not pass inspection, the shrink-wrap cover might be mispositioned and therefore cover either the positive or the negative tip, or the shrink-wrap cover could be applied upside down; stop inspection, and reject the battery. Since misregistration of the shrink-wrap cover is the source of 80 percent of the manufacturer's rejects, checking this target first saves inspection time and increases system throughput.
2. Inspect the shoulder of the battery at the positive end (Target 2). If the target passes inspection, measure the absolute distance between it and Target 1. If it does not pass, the battery could be damaged at the shoulder; stop inspection and reject the battery. If the distance between the two targets is within tolerance, continue. If the distance is not within tolerance, the shrink-wrap cover might be mispositioned and therefore cover either the positive or negative tip; stop inspection and reject the battery.
3. Inspect the positive tip (Target 3). If the target passes inspection, the positive tip is properly formed, of the correct length, and not covered by mispositioned shrink-wrap. Continue inspection. Else, stop inspection and reject the battery.
4. Inspect the negative tip (Target 4). If the target passes inspection, the negative tip is properly formed and not covered by mispositioned shrink-wrap. Inspection decision is *accept*. If the target does not pass inspection, the tip might not be properly formed or could be covered by mispositioned shrink-wrap. Inspection decision is *reject*.

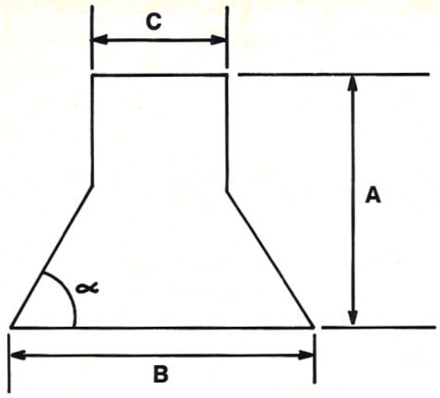

Figure 2. Four measurements are made on a flare for fluorescent light bulbs: the diameter of the hole (C), the diameter of the base (B), length of the flare from hole to base (A), and the angle of the flare at its base (α).

When inspection of a battery is complete, the system signals to a programmable controller that the inspection result is available and then tells the result. If it is *reject*, the controller signals a blower to eject the battery from the line.

Flares for Fluorescent Bulbs. Another system inspects small glass flares that hold the filaments in fluorescent lights. If a flare's dimensions are not within tolerance, the flare will not seat properly in its housing.

This application also uses fiber-optic light delivery; the lead content in the glass causes the flare to glow and provides an outline measurable by the system. Four measurements are made on each flare: the diameter of the hole at one end of the flare (C); the diameter of the base at the other end (B); the length of the flare from hole to base (A); and the angle of the flare at its base (α) (Figure 2).

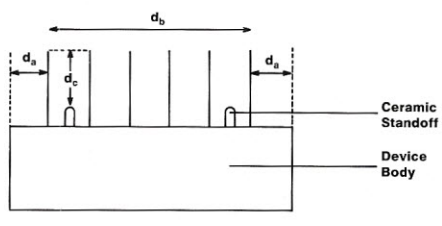

Figure 3. A resistor network is inspected for pin presence and position, ceramic standoffs for presence and shape, and lead length relative to the top of the standoff.

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* *Correspond directly with company*

Resistor Networks. In the electronics industry, a system inspects resistor networks (Figure 3) having six, eight, or ten pins. To determine whether or not a network is within specification, the system

- Inspects the pins to determine that the right number are present (db), that they are located correctly relative to the ends of the body of the device (da), and that they are properly spaced,
- Inspects the network's two ceramic standoffs for presence and proper shape; and
- Inspects lead length as measured relative to the top of the standoff (dc).

During inspection, the network is held by vacuum in a three-sided fixture with its position constrained to ± 0.005 in. in both the x and y dimensions. Leads are positioned up, at 90 degrees, with all leads, the standoffs, and 10 percent of the network body above the fixture. The fixtures are mounted on a rigid steel circle (reel), 36 in. in diameter, which is stepped 5 degrees and then remains stationary for 0.66 sec. A black background in the horizontal plane behind the area to be inspected enhances contrast in the captured image. When the system identifies a reject network it signals the material handling equipment, which removes the bad network from the reel. For this application, the system's nonvolatile memory stores inspectors for four different networks.

ONE INSPECTION APPROACH

Cognex Corporation's Checkpoint 1300 vision system for part quality inspection can perform all three tasks described. This system is pre-programmed to accomplish specific goals, such as inspecting part shapes or measuring distances between a part's visible features (such as edges or notches); then, through a menu interface and using the system camera, an operator trains the system to inspect and measure particular parts according to desired tolerances. Once training is complete, inspection is automatic and an operator can control report generation and changeover from one part type to another through simple keystroke commands. Internal nonvolatile memory allows storage of complete inspection setups.

Because it is important for manufacturers to remove reject parts from the line immediately, the system interfaces to production equipment and indicates its decision (e.g., accept, reject, rework) as an optically isolated signal. The decisions are stored in a first-in, first-out buffer for use downstream in the production line. The system also tallies the number of parts accepted and rejected and classifies rejects by type. It subtotals statistics every hour and saves the results for reports (monitor display or hard copy), which show the subtotals in each category as a function of time of day. Table 1 is an example of an inspection report.

The Inspection Process. A complete inspection involves five steps:

1. Application programming
2. Camera setup
3. Training
4. Operation
5. Report production

Application programming defines inspection goals, telling the system which part features to inspect (e.g., notches, edges, drill holes), how to inspect them (e.g., for absolute or for relative position, for orientation, for shape), what range of tolerances to show for deviations from the ideal, what categories to maintain for rejects, and how to report both accepts and rejects as optically isolated signals.

Combining an application program with an appropriate camera setup, training produces a ready-to-run configuration, called an inspector, that defines exact targets, tolerances, and reports. (The application program then becomes part of the inspector.) During operation, the inspector performs the inspection, produces reports, and controls equipment.

As an example of this relationship, consider a setup for inspecting three different types of parts for presence/absence of a notch, presence/absence of a drill hole, and postion, height, and width of a present drill hole. For all three types of parts, a single application program would define:

- The targets to be inspected,
- The determinations to be made about the targets,
- The units of measure for all positional measurements,
- The reasons for which a part would be rejected, and
- The output signals for accept and reject.

An individual inspector is then created for each part type to store images of specific targets in memory and to set

Table 1
An example of an inspection report from an automated vision system

Time	2	3	4	5	6	7	8	9	10	Totals
Good Part	2000	2320	1567	2500	1988	2244	1500	2127	350	16596
Missing Notch	3	0	100	2	1	0	0	0	1	107
Missing Hole	0	0	0	0	400	0	0	0	0	400
Notch Misposit.	1	2	0	0	0	0	2	5	0	10
Hole Misposit.	0	0	0	0	0	0	0	0	1	1
Hole Diam. Error	0	0	0	3	0	0	58	0	0	61
Trigger Overruns	0	1	0	0	0	0	1	0	0	2
Total Rejects	4	3	100	5	401	0	61	5	2	581
Totals	2004	2323	1667	2505	2389	2244	1561	2132	352	17177

specific position and orientation tolerance values. For example, each part type might have a different size and shape and would therefore have different edge targets. There might also be differences among the parts in notch shape and position and in drill hole size.

Creating an Inspector. Creating an inspector involves setting up the system's electrical interface to other production equipment, positioning the system camera(s), and setting the exact tolerances for a particular part; but the key element in creating an inspector is training specific targets. This is a two-part process: **target training** and **surface calibration.**

Target training defines the specific part features (such as notch or hole) to be inspected by capturing an image of the target and storing an ideal representation of it in memory. During production, the system compares each captured image with the ideal representation to determine how closely the target matches the ideal in terms of position, shape, and contrast.

Surface calibration translates measurements of a target's captured image from the pixels measured by the system hardware into standard units such as mils or inches. This is an important system feature, because while a flat surface produces a good correspondence between pixels and standard units of measure, a curved surface, such as a cylindrical part, distorts the correspondence. Surface calibration compensates for that distortion.

System Operation. During operation, the system operates in an acquire-process-report cycle.

1. The camera acquires an image of the part to be inspected and sends analog video signals to the processor, which digitizes the signals into a gray level image.
2. The system searches this image for the targets defined during training. It determines the presence/absence of each target, and, if a target is present, determines its image coordinates. It also determines each target's appearance quality, appearance contrast, and deviation from expected position in surface coordinates. It then compares these measured values with the tolerances set by the user, and determines the extent to which the inspected part meets the designated quality standards.
3. Finally, the system reports the actual measured values taken on each target and its accept/reject decision for the entire part. The inspection results can be displayed on the monitor and are transmitted as an optically isolated signal to a chosen destination.

CONCLUSION

The demand for improved quality assurance in industrial manufacturing continues to mount, and vision technology continues to develop in terms of both speed and capability. In the future, machine vision systems will continue to provide the fast, accurate inspection solutions needed in the industrial market.

Mary E. Doyle manages technical writing for Cognex Corporation.

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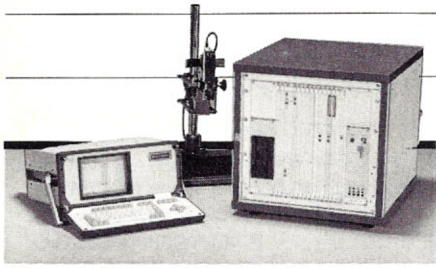
7	17	27
Excellent	Good	Fair

New Products



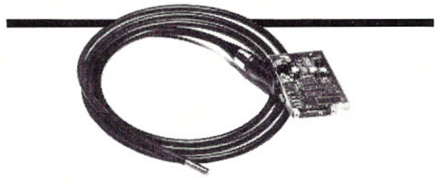
Expert Programmable Vision System Checks for Conformity to Specs

The Bulletin 2805 Expert Programmable Vision System (PVS) uses artificial vision to recognize and inspect components or products for conformity to specifications. The system has applications for robot guidance and general surveillance as well. Using a modular architecture, the system operates in basic applications as a low-end unit and, with the addition of other coprocessors, as a high-end unit for more complex applications.

The system accepts input from one to eight video cameras. Modular PCBs can be used for data acquisition, preprocessing, processing, external communication, and system supervision.

The special purpose coprocessors, each of which can act on a separate set of data simultaneously, allow the system to perform image acquisition and preprocessing, contour extraction, segmentation and processing, and external communication in parallel. A mathematical morphology has also been incorporated.

For more information, contact: Allen-Bradley Company, Industrial Control Division, Dept. ICN/85-47, 1201 S. Second St., Milwaukee, WI 53204, telephone (414) 671-2000. Circle 101

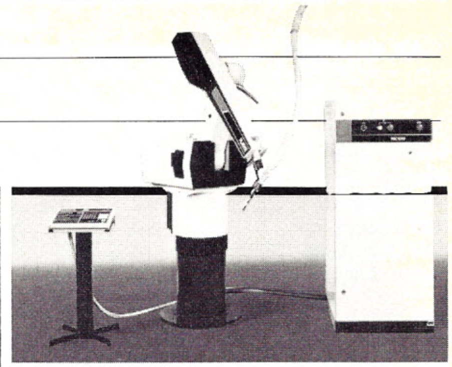


Small Solid-State Imaging Component Does Not Hamper Robot Movement

A solid-state machine vision imaging component that includes an ultra-miniature CCD imaging chip, a flexible probe, and solid-state circuitry for image processing is now available. A CCD sensor, embedded in the tip of the probe, transmits a superior, high-resolution image of 31,000 pixels that can be integrated into existing image processing equipment including computers, video processors, and digital signal converters.

The device is designed for use as a sensing component by designer-manufacturers of machine vision equipment for robotics, automatic testing, pattern recognition, and other machine vision or monitoring applications. It is said to be ideal for robotic applications where its small design and light weight do not hamper robot movement, lifting, or sensing capabilities, and can replace larger vision system cameras currently in use for such applications.

For more information, contact: VideoProbe Division, Welch Allyn, Inc., 4341 State Street Rd., PO Box 220, Skaneateles Falls, NY 13153-0220. Circle 102



Robotic Welding System Handles Small Batches and Custom Jobs

The FlxWeld robotic welding systems are designed for use in construction equipment, material handling, automotive components, and metal fabrication, in both small-batch production and custom applications. Cartesian coordinate, articulated arm, and SCARA-type systems can perform regular solid-wire GMAW, pulsed GMAW, gas-shielded flux-cored wire, and self-shielded processes. FlxWeld's RSC 1000 control is engineered to allow all required teaching and operating functions to be performed from a single remote panel, with up to 99 types of workpiece patterns programmed. The torch automatically moves in a straight line between two points once the points are taught. Extended welding controls provide a complete range of optional requirements from torch and arc sensors to external work number callout.

For more information, contact: Sciaky Bros., Inc., member company of Allegheny International, Inc., 4915 W. 67th St., Chicago, IL 60638, telephone (312) 594-3800. Circle 104

Seam Finding Sensor System Talks to Robot Controller

The ASEA seam finding system consists of an optical sensor and a microcomputer that evaluates the sensor signals and transmits the result to the adaptive functions in the robot control system. In the searching process, the joint is defined in three dimensions and the welding gun is positioned simultaneously. A complete search in three dimensions and location of the gun takes approximately 1.5 sec. A search in two dimensions is often sufficient and is performed without actuation of the arc.

The system can be used in most welding applications. It is, however, particularly appropriate for welding thin sheets with many short welds where short cycle times are required (e.g., in welding car bodies or the details of bodies and wheel suspensions). It is the first sensor system available for this type of industrial application.

Features of the ASEA seam finder include noncontact, accurate, and rapid localization of the joint; the use of wider tolerances in the dimensions and positioning of the workpiece; a measurement unaffected by the nature of the surface, the presence of rust, oil, paint, and the sheet thickness; measurement of the gap and adaptation of the welding data when welding overlap joints; and insensitivity to light intrusions from the arc and the surroundings. Optical sensor specifications are: weight, 650 g; measurement distance, 170 mm; measurement range, 32 mm; and resolution, 0.06 mm. The system has a search accuracy of ± 0.4 mm; a search time (three dimensions) of 1.5 to 2.0 sec.; and search types for height, edge/overlap, joint, fillet joint, and gap measurement.

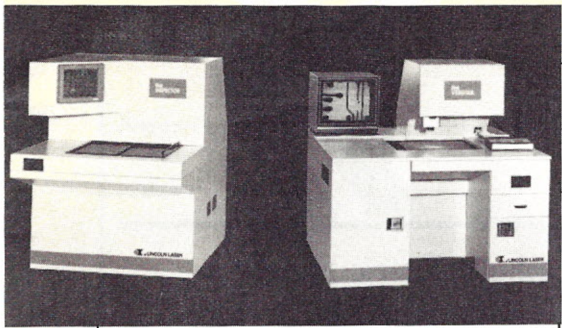
For more information, contact: ASEA Robotics Inc., 16250 W. Glendale Dr., New Berlin, WI 53151, telephone (414) 785-3400. Circle 105

Machine Vision Systems Use Real-Time Image Preprocessors

A new series of machine vision systems based on the IBM PC uses ITMI's GTR real-time image preprocessors. The V2D system incorporates the GTR 2D, which, based on a standard video input, digitizes 64 levels of gray and extracts the location of contrast points (edges) for a 256 by 256 matrix in real time; a parallel interface; and CAIMAN software. V3D incorporates the GTR 3D, which extracts the edge of a structured light plane and provides the location of these laser pixels in real time; a parallel interface, and L3D software.

For more information, contact: Sal D'Agostino, Vice President, Marketing, Industrial Technology and Machine Intelligence, 1000 Massachusetts Ave., Cambridge, MA 02138, telephone (617) 576-2585. Circle 106

New Products



Inspection System Detects Defective PCBs

The Inspector/Verifier is an automated optical inspection system for detection and inspection of defects in printed circuit boards—regardless of conductor surface quality. Tarnished, soldered, or sanded conductor surfaces cause the typical optical scanner to give false defect readings. The laser scanning approach of the system avoids this common problem because the system is not dependent on the cosmetic quality of the conductor surface to achieve accurate results.

By using a finely focused laser beam to fluoresce the substrate of the printed circuit board, the system can examine any conductor surface for defects such as opens and shorts, nicks and pinholes, and out-of-tolerance conductor width and spacing. Information about these defects—in the form of a defect location map—is then stored on a floppy disk for use with the Verifier.

The Verifier subsystem is designed for quick visual confirmation of any defects detected by the Inspector. It incorporates such features as automatic location of identified defects, magnified monitor image, flexible operator controls, and the ability to make on-the-spot repairs.

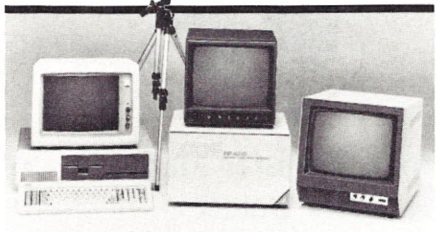
For more information, contact: Lincoln Laser Company, 234 E. Mohave, Phoenix, AZ 85004, telephone (602) 257-0407. Circle 107

Options for Bulk Weldwire System Improve Positioning Capabilities

New options are available for the RCD System, a bulk weldwire system designed for robotic and other high-speed welding operations. A four-wheel cart has been developed to hold the system, permitting the welder or other personnel to move it for better positioning within the welding cell. An aluminum cap with polyethylene curtain shields the wire from the industrial welding environment.

A self-centering base automatically centers a coil being lowered on the pallet beneath the RCD System, making changeovers easier and faster for more arc time.

For more information, contact: Customer Service Department, National-Standard Welding Products Division, Niles, MI 49120, telephone (800) 253-1318. Circle 110



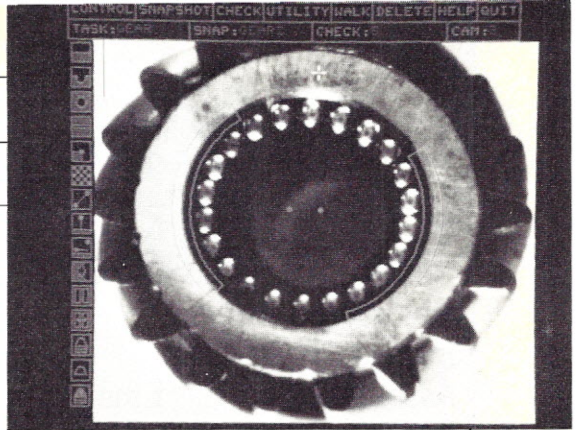
Flexible Image Processor Runs on a PC

Model PIP-4000 is a new flexible image processor designed to be used with a personal computer for machine vision high-speed inspection systems, computer-integrated manufacturing, and other automated monitoring and quality control operations. It is especially suitable for applications where it is necessary to monitor a variety of digitized video functions in real time such as in the analysis of metals or composite materials for hidden stress, flaws or fatigue, and to simultaneously check parts for quality parameters as they move along a mechanized conveyor system.

Several available interactive software programs include specialized packages for moire edge enhancement, particle distribution measurement and anaylsis, or Fast Fourier image modification.

The processor can handle as many as eight TV cameras simultaneously and has an image memory of up to 512 by 512 by 8-bit by 32 frames, depending on configuration. Other hardware options include array processors and modules for true, full-color operations, or complex filtering.

For more information, contact: Alison Clayton, A.D.S. Imaging Systems, 467 Hamilton Ave., Suite 2, Palo Alto, CA 94301, telephone (415) 322-8450. Circle 108



Inspection System Adjusts to Position and Lighting Variations

ARGUS™ is a modular, high-speed inspection system that performs dimensional gauging, complex assembly verification, and three-dimensional part inspection. It is designed to automate and strengthen quality assurance applications for the automotive, electronics, aerospace, and general manufacturing industries.

The system performs 100 percent quality control assembly inspection by verifying the presence or absence of parts, dimensions, and tolerances. It examines parts using proprietary mathematical algorithms to detect edges and other critical features and automatically adjusts to any variations in position or location of the part on the production line. It can be used as a standalone system or as an easily integrated part of a large CIM system.

The system features descriptive, easily recognizable icons, color graphics, and a factory-rugged trackball interface. ARGUS uses the Vision Ladder Logic in a nonconstraining, spreadsheet format that lets users continue logic from screen to screen without interruption. Its open architecture is based on the 32-bit Motorola 68010 processor and the industry standard VMEbus.

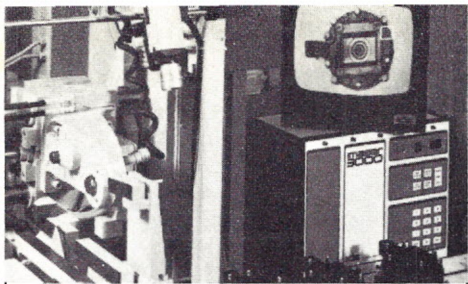
For more information, contact: American CimFlex Corporation, 121 Industry Dr., Pittsburgh, PA 15275, telephone (412) 787-3000. Circle 109

Parallel Processor Chip Detects Binary and Gray Scale Images

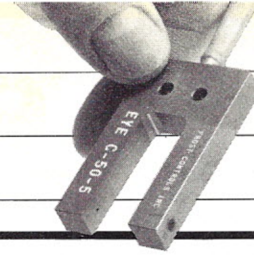
The Geometric Arithmetic Parallel Processor chip is a parallel processing integrated circuit. On each chip are 72 processing elements in a 12 by 6 array that operate concurrently to solve parallel processing problems. Each element executes the same instruction simultaneously while operating on its own data, and it can communciate with its four neighboring elements, north, south, east, and west, a desirable characteristic in many parallel processing applications.

In effect, each processing element is aware only of elements in its local neighborhood. This property allows designers to directly cascade chips to form larger arrays of processing elements without complicated interface logic. From a software standpoint, the fact that the GAPP chip allows an entire image, or portion of an image, to be processed in parallel allows software designers to create hardware-independent software.

For more information, contact: NCR Corporation, Microelectronics Division, 2001 Danfield Court, Ft. Collins, CO 80525, telephone (303) 226-9550. Circle 111



New Products

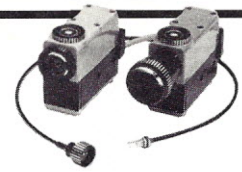


Automated System Inspects Parts and Assemblies on the Line

The IMAGER 3000 inspects parts and assemblies on automated production lines for correct fabrication and assembly. It consists of a processor, video camera and lens, lighting, I/O, and a monitor and terminal. It can also monitor production machinery and sort and count parts.

The system offers 100 percent noncontact inspection for process control or quality assurance at speeds of up to 15 parts/sec. IBM (or compatible) PCs can be used to set up inspection tests and to store inspection tests on disk, facilitating test retrieval and replacement. The Imager stores up to 200 tests in its nonvolatile memory. Additional tests can be stored on magnetic tapes using an optional tape drive.

For more information, contact: Dallas Maddox, Monitor Automation, 315 W. Huron, Ann Arbor, MI 48103, telephone (800) 843-3380 or (800) 342-8133 (in Michigan). Circle 118



Color Register Mark Scanners Detect Slight Color Difference

The TL Series Color Register Mark Scanners are designed to differentiate between different colors. The unique optical system enables these units to detect slight color differences—yellow on white—or even different shades of the same color. The scanners can be used to sort objects by color, or detect color registration marks in the printing, paper, and packaging industries. For hard-to-reach or hazardous installations, the TL Series Color Register Mark Scanners are also available with fiber optics.

For more information, contact: Herb Ruterschmidt, Datalogic Optic Electronics, Inc., 20340 Center Ridge, Rocky River, OH 44116, telephone (216) 331-9300. Circle 119

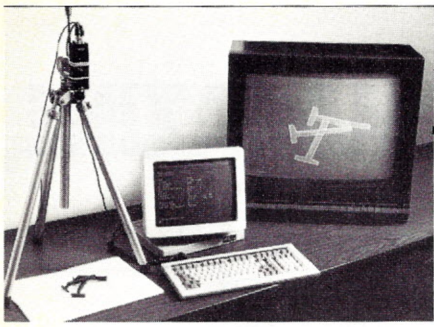
Photoelectric Sensor System Detects Miniature Objects Quickly

EYE-C Series sensors are a self-contained photoelectric system capable of detecting very small objects quickly. The photoelectrics consist of an infrared LED light source, a high-speed photodiode receiver, amplifying circuitry, Schmitt trigger, voltage regulator, current regulator, and output transistor. The output transistor provides logic level switching of its 5 VDC or 12 VDC power supply. The system has a response time of 50 μs, and is factory set for detection of objects as small as 0.012 in. in diameter. Smaller object (0.008 in. in diameter) detection can be achieved by adding an auxillary resistor. Typical applications include automatic insertion equipment, automatic assembly equipment, robots, and pick and place machinery.

For more information, contact: Robert Thomson, Sales Manager, Frost Controls, Inc., Industrial Drive South, Smithfield, RI 02917, telephone (800) 437-7689. Circle 120

Circle 46

New Products



Direct-connect Vision Systems Identify and Locate Stationary Objects

Two new vision systems designed to handle the majority of robotic applications requiring vision are now available. Univision III is an area vision system used to identify and locate stationary objects. Conveyorvision is a line-scanning vision system designed to identify moving objects on a conveyor and determine their locations relative to the conveyor. Both can identify touching and overlapping parts.

The systems are designed for use with Unival™, Unimation's new robot controller. As options to Unival, the systems become an integral part of the controller. No interfacing is required and they come with preprogrammed software. Communication time is reduced, as the systems are directly on Unival's main computer bus.

Using the teach-by-showing method, both systems allow users to program the robot to identify various parts. Univision III can be used with multiple cameras to meet a wide range of robot vision requirements.

For more information, contact: Unimation Incorporated, Shelter Rock Lane, Danbury, CT 06810, telephone (203) 796-1069. Circle 112

Vision Measurement System Allows Programming by Menu

The View 1220 is suited for inspection of reflective and translucent parts, black plastic parts, cylinders, shafts, ceramic parts, and stampings. Its Menu Programmable Language (MPL) allows the user to write measurement programs entirely by menu, using a joystick controller to make menu selections. Once written, programs can be edited by line or character. Color graphics and unique measurement tools add to programming ease and flexibility.

The View 1220 employs 256-level gray scale processing and new edge detection algorithms to accurately detect edges, despite variances in lighting or surface finish. A new ring light, called an articulated toroid, allows the user to automatically control the direction and intensity of peripheral light. The through-the-lens light source is equipped with an LCD Ronchi Grid that aids in focusing on reflective or translucent parts. An exclusive retroreflective system eliminates the need for back lights. The system's accuracy is improved by subpixeling capabilities that increase resolution up to ten times for dimensional measurement and alignment.

For more information, contact: View Engineering, Inc., 1650 N. Voyager Ave., PO Box 8101, Simi Valley, CA 93063, telephone (805) 522-8439. Circle 113

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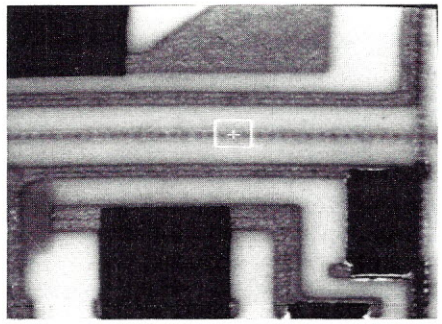
* Exhibitors as of January 10, 1986

New Products

Inspection Aid Finds Laser Scribe Lines on Hybrid Substrates

A new inspection aid determines the location of laser scribe lines on hybrid substrates. This add-on software package for the V20 Workstation features simple, menu driven instructions that require no computer experience. With the software, the vision system can be taught to recognize both horizontal and vertical laser scribe lines, and determine if they are properly located relative to the pattern or substrate edges. A step-and-repeat program is available as a standard feature that allows the single taught horizontal or vertical scribe line to be used for inspecting repetitive patterns.

An operator need only identify the desired test or part number, place the substrate upon the x-y table, and activate the test. The V20 Workstation vision system automatically inspects for alignment, calculates any deviations from standard, and reports results on the monitor. Standard accuracy is 0.5 mils. A hard copy of the alignment can be made on a standard



line printer.

The complete test can be accomplished in seconds for most applications. Special programming can provide for automatic calculation of machine adjustment instructions that the operator can implement for process control. The alignment data can be optionally sent to the laser scribing machine over a serial port.

For more information, contact: Dennis E. Meyers, Vice President, Sales & Marketing, Photonic Automation, Inc., 3633 W. MacArthur Blvd., Santa Ana, CA 92704, telephone (714) 546-6651. Circle 114

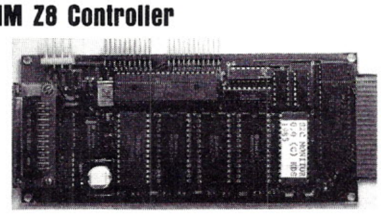
In-line Inspection System Looks for Flaws in Connectors

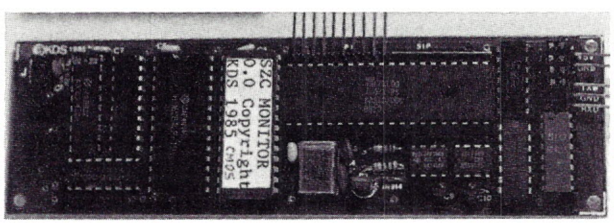
A new laser inspection system for electronic connectors looks for IDC gap, pin height, row-to-row spacing, true pin position, and missing contacts. It has speeds of 500 to 1000 linear in./min., depending on line speeds and part configuration.

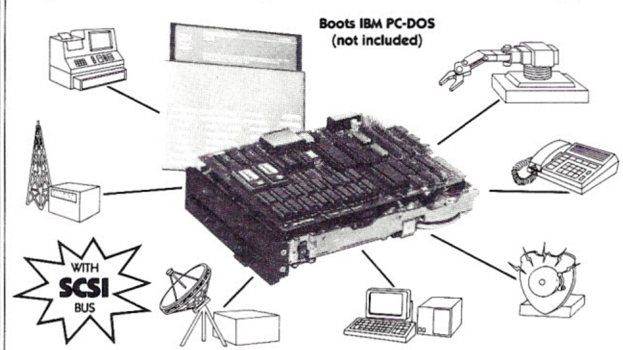
Inspections are performed on both of the connector rows (top side and bottom), depending on requirements. Static laser beams or scan lines are triangulated off the contacts/pins during the process. The reflected laser light is received by sensitive photodetectors; these signals are digitized and processed by ASI's standard electronic circuitry. The processed information is compared to preset information for verification.

Setup for a dedicated family of different-sized parts requires a simple track adjustment and re-entry of new part data information, and can be accomplished in 10 to 15 minutes.

For more information, contact: Automation Systems, Inc., 1106 Federal Rd., Brookfield, CT 06804, telephone (203) 775-2581. Circle 115







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Circle 34

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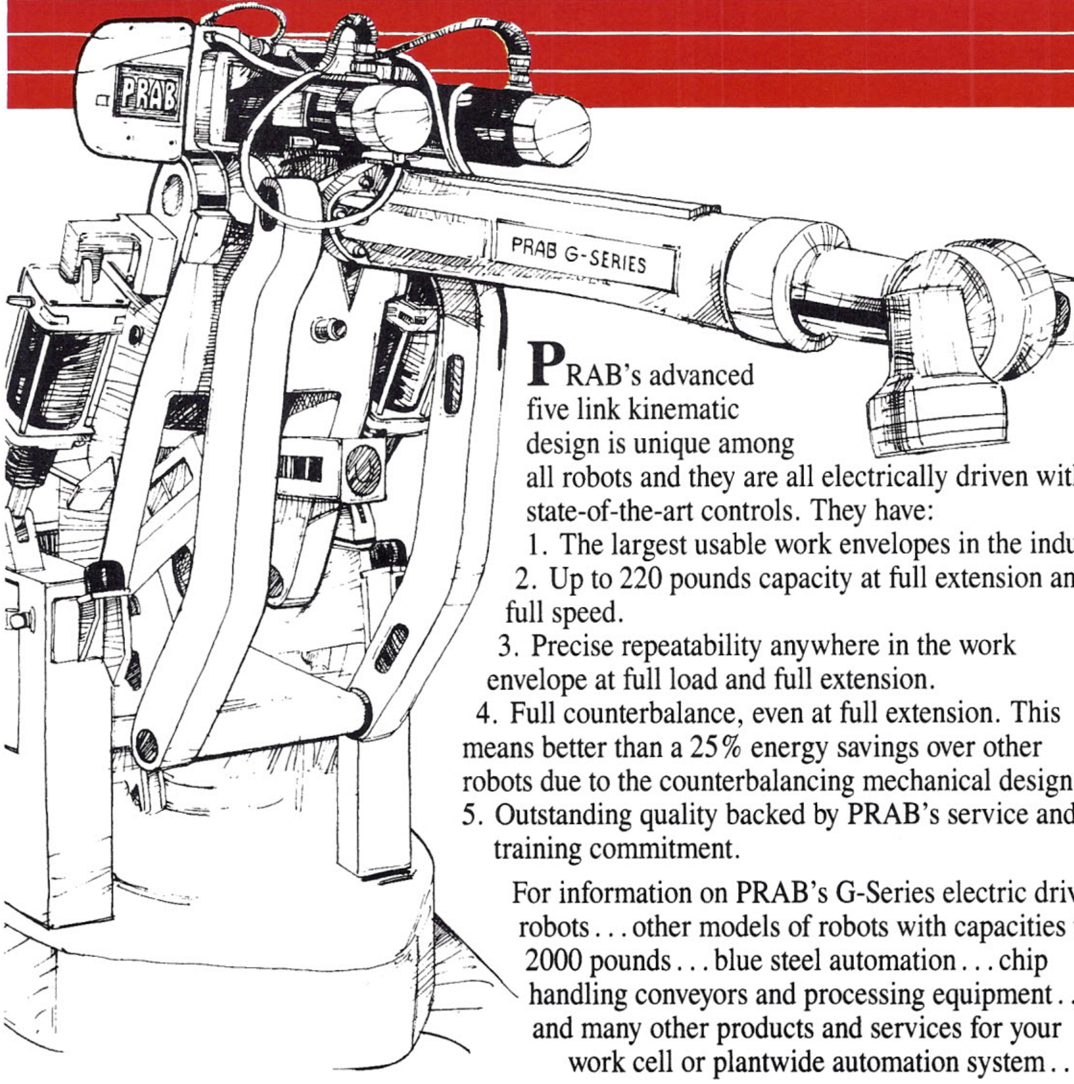

PRAB's advanced five link kinematic design is unique among all robots and they are all electrically driven with state-of-the-art controls. They have:

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AutoNetics announces a Spectrum of Solutions for small parts handling and assembly.

☐ Fully programmable assembly stations with capabilities that match your needs.

☐ Reconfigurable assembly cells that can be reused even if your future involves radical product changeovers.

☐ Reliable assembly stations that work consistently through their long service lives and can be serviced quickly and economically with standardized replacement parts.

AutoNetics manufactures and distributes the Bosch line of pre-engineered handling and assembly modules. This proven equipment is fully programmable, reconfigurable, reuseable, reliable and cost-effective.

This Equipment is Available from AutoNetics in Two Ways:

☐ As separate modules which your systems integrator can assemble into custom cells.

☐ As pre-engineered and pre-assembled custom cells ready for your systems integrator to link up and position along your transport line.

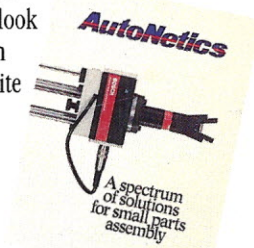
Either way, your automated assembly cells are made up of interchangeable, programmable modules. The modules range from simple pneumatic or electric linear slides to Cartesian units and a family of SCARA robots. There are pick and place modules, soldering, screwing and gluing modules and a variety of adapter plates to provide exactly the movement orientations you require.

A full spectrum of automated handling and assembly products, all available off-the-shelf using a simple ten-digit ordering code.

And because the modules are standardized manufactured items, they are highly reliable and serviceable...a fact proven through years of use.

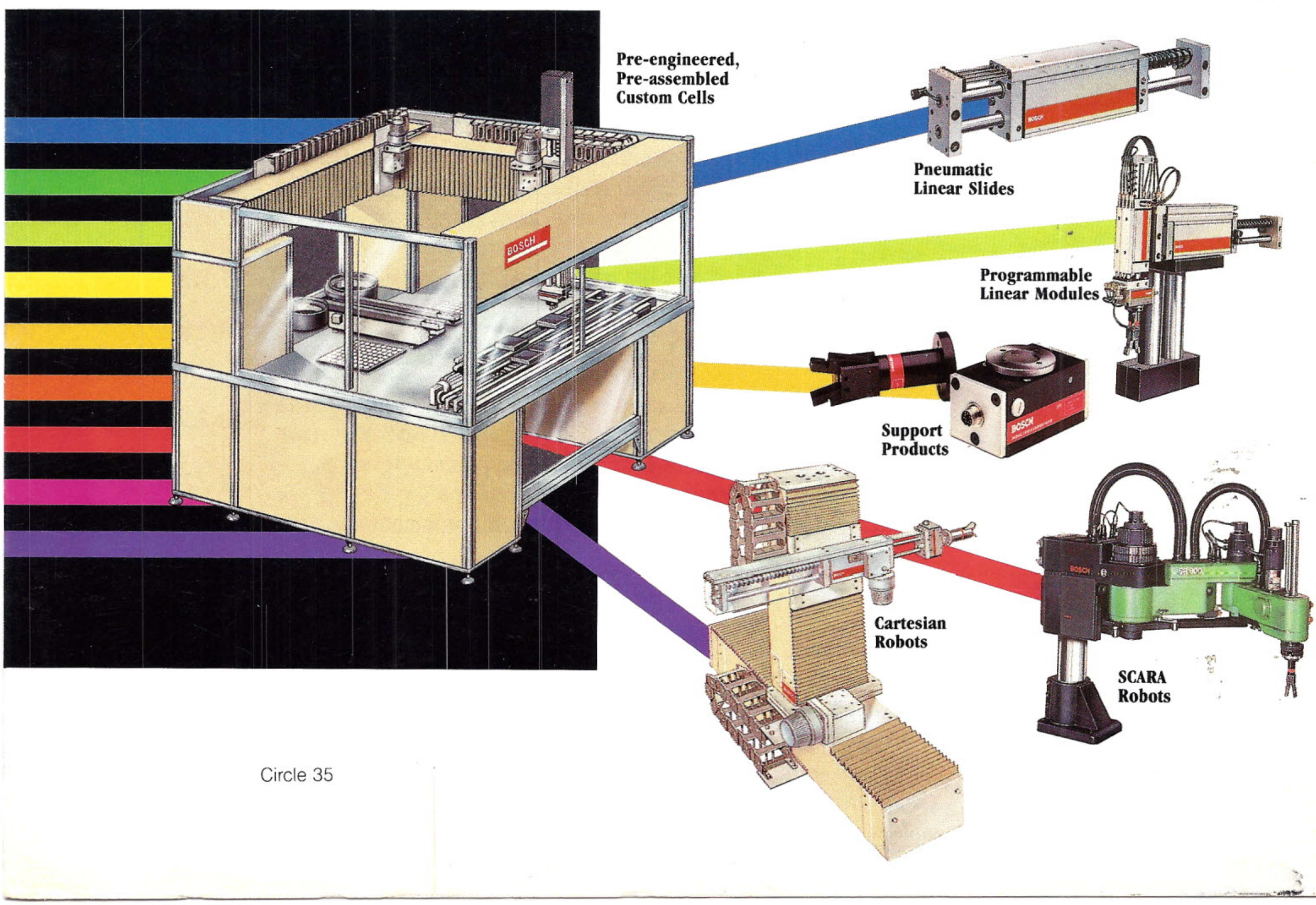
AutoNetics provides expert application engineering services to support the selection, specification, custom configuration and assembly of this equipment.

For a closer look at our Spectrum of Solutions, write AutoNetics, P.O. Box 373, St. Joseph, MI 49085.



AutoNetics

A Spectrum of Solutions for Small Parts Assembly



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